XII

ON A SELF-RECOVERING COHERER AND THE STUDY OF THE COHERING ACTION OF DIFFERENT METALS

In working with coherers, made of iron or steel, some special difficulties are encountered in the warm and damp climate of Bengal. The surface of the metals soon gets oxidised, and this is attended with variation of sensitiveness of coherer. The sensitiveness, it is true, does not altogether disappear, but it undergoes a considerable diminution. The presence of excessive moisture in the atmosphere introduces another difficulty. Substances to be experimented on become more or less opaque by absorption of water vapour. As fairly dry weather lasts in Bengal only for a few weeks in winter, the difficulties alluded to above are for the greater part of the year serious drawbacks in carrying out delicate experiments. To avoid as far as possible the partial loss of sensibility of the receiver due to oxidation, I tried to use metals less oxidisable than iron for the construction of the coherer. In my earlier experiments I derived considerable advantage by coating the steel spirals with deposits of various metals. Finding that the sensitiveness depends on the coating metal and not on the substratum, I used in my later experiments fine silver threads wound in narrow spirals. They were then coated with cobalt in an electrolytic bath. The coating of cobalt was at first apt to strip off, but with a suitable modification of the electrolyte and a proper adjustment of the current, a deposit was obtained which was very coherent. The

contact surface of cobalt was found to be highly sensitive to electric radiation, and the surface is not liable to such chemical changes as are experienced in the case of steel.

I next proceeded to make a systematic study of the action of different metals as regards their cohering properties. In a previous paper I enumerated the conditions which are favourable for making the coherer sensitive to electric radiation. These are the proper adjustment of the E. M. F. and pressure of contact suitable for each particular receiver. The E. M. F. is adjusted by a potentiometer slide. For very delicate adjustments of pressure I used in some of the following experiments an U-tube filled with mercury, with a plunger in one of the limbs; various substances were adjusted to touch barely the mercury in the other limb. A thin rod, acting as a plunger, was made to dip to a more or less extent in the mercury by a slide arrangement. In this way the mercury displaced was made to make contact with the given metal with gradually increasing pressure, this increase of pressure being capable of the finest adjustment. The circuit was completed through the metal and mercury. Sometimes the variation of pressure was produced by a pressure bulb. In the arrangement described above the contact is between different metals and mercury; metals which were even amalgamated by mercury still exhibited sensitiveness to electric radiation when the amalgamation did not proceed too far. In this way I was able to detect the cohering action of many conductors, including carbon. For studying the contact-sensitiveness of similar metals I made an iron-float on which was soldered a split tube in which the given metal could be fixed, a similar piece of metal being adjusted above the float, so that by working the plunger or the pressure bulb the two metals could be brought into contact with graduated pressure. The other arrangements adopted were the contact of spirals compressed by micrometer screw, and filings similarly compressed between two electrodes.

With the arrangement described above the action of radiation on metallic contacts was studied, a brief account of which will be given under their respective groupings. It may here be mentioned that certain metals which do not usually show any contact-sensitiveness can be made to exhibit it by very careful manipulation. The nature of the response of a coherer is to a certain extent modified by its condition and particular adjustment. A coherer freshly made is more difficult to adjust, but at the same time far more sensitive. The action is more easily under control and more consistent after a few days' rest, but the sensitiveness is not so abnormally great. The contacts of clean surfaces are difficult to adjust, but such contacts are more sensitive than those made by surfaces which are tarnished. Pressure and E. M. F., as previously stated, also modify the reaction. For example, a freshly made and very delicately adjusted coherer subjected to slight pressure and small E. M. F. showed an *increase* of resistance by the action of radiation. The galvanometer spot after a short interval, resumed its former position, exhibiting a recovery from the effect of radiation. The coherer continued to exhibit this effect for some time, then it relapsed into the more stable condition in which a diminution of resistance is produced by the action of radiation.

Another coherer was found apparently irresponsive to radiation, there being the merest throb (sometimes even this was wanting) in the galvanometer spot, when a flash of radiation fell on the receiver. Thinking that this apparent immobility of the galvanometer spot may be due to response, followed by instantaneous recovery, the galvanometer needle being subjected to opposite impulses in rapid succession, I interposed a telephone in the circuit ; each time a flash of radiation fell on the receiver the telephone sounded, no tapping being necessary to restore the sensitiveness. The recovery was here automatic and rapid. After twenty or thirty flashes, however, the receiver lost its power of automatic recovery, and the sensitiveness had then to be restored by tapping. An interesting observation was made to the effect that on the last occasion the receiver responded without previous tapping, a rumbling noise was heard in the telephone which lasted for a short time, evidently due to the rearrangement of the surface molecules to a more stable condition, after which the power of self-recovery was lost.

The state of sensibility described above is more or less transitory, and is induced, generally speaking, by a somewhat unstable contact and low E. M. F. acting in the circuit. In the majority of metals, the normal tendency is towards a diminution of contact resistance by the action of electric waves. The occasional increase of resistance, in general, disappears when the pressure and E. M. F. are increased. But in the case to be presently described there is an interesting exception, where the normal state of things is just the reverse of what prevails in the majority of metals.

Alkali Metals

In the following investigations the radiator is a platinum sphere 9·7 mm. in diameter. The coherer was placed at a short distance, so that the intensity of incident radiation was fairly strong.

Potassium.—In working with this metal, the exceptional nature of the reaction became at once evident. The effect of radiation was to produce an *increase* of resistance. The pressure of contact was adjusted till a current flowed through the galvanometer, the galvanometer spot of light being at one end of the scale. On subjecting the receiver to radiation the spot of light was deflected to the opposite end, exhibiting a great increase of resistance. When the pressure and E. M. F. were suitably adjusted a condition was soon attained, when a flash of radiation made the spot of light swing energetically in one direction, indicating an increase of resistance: the receiver recovered instantaneously on the cessation of radiation, and the spot violently swung back to the opposite end, indicating the normal current that flows in the circuit. This condition was found to persist, the receiver uniformly responding with an increase of resistance followed by automatic and instantaneous recovery. To prevent oxidation, the receiver was kept immersed in kerosene. When the receiver was lifted from the protecting bath, it still continued to respond with an increase of resistance, but with a gradual loss of power of automatic recovery. This power was again restored on re-immersion of the coherer in kerosene. The receiver in vacuo, or under reduced hydrogen pressure, would have been preferred, had the necessary appliances been available.

Sodium.—As we pass from potassium to the neighbouring metals, there is a gradual transition of property as regards the nature of response to electric waves. With sodium the adjustment is a little more difficult than with potassium, but the response is somewhat similar to that of potassium. Though, in general, there is an increase of resistance produced by electric radiation, there are occasional exceptions when a diminution of resistance is produced. With some trouble the adjustment could be made so that the recovery is also automatic, but it is not so energetic as in the case of potassium.

Lithium.—Specimens of this metal not being available, I obtained a deposit of it on iron electrodes by electrolysis of the fused chloride. The action produced by electric radiation was sometimes an increase and sometimes a diminution of resistance, the increase of resistance being the more frequent. With some difficulty it was possible to adjust the sensitiveness so that the recovery was automatic, but it was not energetic nor did this power persist for a long time.

Metals of the Alkaline Earth

Pure metals of this group being not available, I had to rely on the deposit obtained by electrolysis. Chloride of calcium was fused in a crucible, and deposits were produced on iron cathodes, the anode being a carbon rod. The deposit was not very even. One of the iron rods with the deposit was tested by immersion under water, when hydrogen was evolved. I did not succeed in getting deposits of either barium or strontium, the temperature available not being sufficiently high.

On making a coherer with calcium, and keeping it immersed in kerosene, an action similar to that produced by sodium was observed. The tendency of self-recovery was, however, very slight.

Magnesium, Zinc, and Cadmium

In these metals and in the succeeding groups there is a pronounced tendency towards a diminution of resistance by the action of electric radiation. Magnesium being easily oxidisable, there is a thin coating of oxide on the surface. When this is scraped, the metal makes a very highly sensitive receiver. The adjustment is not difficult, the metal allowing a considerable latitude of pressure and E. M. F. It has already been stated that the metals which are slightly tarnished can be more easily adjusted.

Though there is in this metal a decided tendency towards a reduction of contact resistance, yet it is possible by careful adjustment to obtain an increase of resistance. Indeed it is sometimes possible to so adjust matters that one flash of radiation produces a diminution of resistance, and the very next flash an increase of resistance. Thus a series of flashes may be made to produce alternate throws of the galvanometer needle. The more stable adjustment, however, gives a diminution of resistance, and receivers made with this metal could be made extremely sensitive. The tendency towards automatic recovery is almost wanting.

Zinc.—This metal also exhibits moderate sensitiveness; it, however, requires a more careful adjustment.

Cadmium.—The action of this metal is somewhat similar to that of zinc, but the sensitiveness is very much less.

Bismuth and Antimony

Both bismuth and antimony make very sensitive receivers. Moderately small E. M. F. with slight pressure is best suited for these metals.

Iron and the Allied Metals

Iron.—The action of this metal is well known. In one of my experiments I used it in connection with mercury. When the contact is very lightly made, there is a tendency towards an increase of resistance by the action of radiation. But after a time the action becomes normal, that is to say, there is a diminution of resistance.

Nickel and Cobalt.—These are also very sensitive. The surface being bright, the E. M. F. and pressure are to be adjusted with some care.

Manganese and Chromium.—These were obtained in the form of powder. Their action is similar to the other metals of this group.

Aluminium.—This also makes a very sensitive receiver.

Tin, Lead and Thallium

It is somewhat difficult to adjust *tin*, but when this is done the metal exhibits fair sensitiveness. *Lead* is also sensitive. The sensitiveness of *thallium* is only moderate.

Molybdenum and Uranium

The specimen obtained was in the form of powder, and very tarnished in appearance. The sensitiveness exhibited was slight.

Metals of the Platinum Group

Platinum exhibited a moderate amount of sensitiveness. Spongy platinum also showed the same action. The absorption of hydrogen made the action slightly better, but the improvement was not very marked.

Palladium.—This made a more sensitive coherer than platinum. The adjustment is, however, more troublesome.

Osmium.—The specimen was in the form of powder. It required a higher E. M. F. to bring it to a sensitive condition. The sensitiveness was moderate.

Rhodium was found to be more sensitive than osmium.

Copper, Gold and Silver

Copper required a much smaller E. M. F. The sensitiveness was only moderate.

Gold was more difficult to adjust, but the action was a little stronger.

Silver.—The receiver was extremely unstable. It exhibited sometimes a diminution and at other times an increase of resistance.

It will be seen from the above that all metals exhibit contact-sensitiveness to electric radiation, the general tendency being towards a diminution of resistance.

The most interesting and typically exceptional case, however, is the receiver made with potassium, which not only exhibits an increase of resistance by the action of radiation, but also a remarkable power of self-recovery. In the instances of increase of resistance exhibited by other metals, an increase of pressure or E. M. F. generally brought the coherer to the normal condition, which showed a diminution of contact resistance by the action of electric waves. With potassium I gradually increased the pressure till the receiver grew insensitive. All along it indicated an increase of resistance, even when one piece was partially flattened against the other. I increased the E. M. F. many times the normal value ; this increase (till the limit of sensitiveness was reached) rather augmented the sensibility and power of automatic recovery. I allowed the receiver a period of rest, the nature of response remaining the same. As far as I have tried, potassium receivers always gave an increase of resistance, a property which seems to be characteristic of this metal, and to a less extent, of the allied metals.

It will thus be seen that the action of potassium receiver cannot be regarded as a cohering one. For it is difficult to see how a cohering action and consequent better contact could produce an increase of resistance.

In arranging the metals according to their property of change of contact resistance, I was struck by the similarity of action of electric radiation on potassium in increasing the contact resistance, and the checking action of visible radiation on the spark discharge. In the latter case also, potassium is photo-electrically the most sensitive. But the action is confined to visible radiation, and is most efficient in the ultra-violet region. I was indeed apprehensive that the action on potassium receiver which I observed might be in some way due to the ultra-violet radiation of the oscillatory spark. But this misgiving was put to rest from the consideration that the receiver was placed in a glass vessel filled with kerosene, through which no ultra-violet light could have been transmitted. For putting the matter to final test, I lighted a magnesium wire in close proximity to the receiver without producing any effect. Thick blocks of wood, of ebonite and of pitch were interposed without checking the action. I then used polarised electric radiation, and interposed a book analyser, 6 cm. in thickness; when the analyser was held parallel, there was a vigorous action, but when it was held in a crossed position all action was stopped. No visible or heat radiation could have been transmitted through such a structure, and there can be no doubt that the action was entirely due to electric radiation.

(*Proc. Roy. Soc.*, *Apr.* 1899.)

XIII

ON ELECTRIC *TOUCH* AND THE MOLECULAR CHANGES INDUCED IN MATTER BY ELECTRIC WAVES

In the various investigations on the properties of electric waves, one property has not yet attracted so much attention as it deserves—the action of long ether waves in modifying the molecular structure of matter. Apart from the interest attached to the relation between ether, electricity, and matter, the subject is of importance as affording not only a very important verification of the identity of visible and electric radiation, but also establishing the continuity of all radiation phenomena. These occupy the borderland between physics and chemistry, and their study may therefore be expected to throw much light on several subjects at present imperfectly understood. The study of the action of electricity and of ether waves on matter in the form of solids presents many difficulties, owing to the great complexity of atomic and molecular aggregation which characterises the solid state of matter. But the phenomena often met with in theory and practice are, unfortunately, in reference to matter in the solid state. The means of investigation are almost wanting: chemical tests give us no information, for they tell us (and that in a few cases only) of the ultimate change in the mass as a whole, and not of the protean transformations that are constantly taking place in it under the action of ever-varying changes in physical environments. In the following investigations the difficulties mentioned above were constantly present, and the attempts to meet them may therefore be of some interest.

I have already described the contact-sensitiveness of various elementary substances to electric radiation. It was shown that though many substances exhibit a diminution of contact-resistance, there are others which show an increase of resistance which, in certain cases, lasts only during the impact of electric waves, the sensitive substance automatically recovering its original conductivity on the cessation of radiation. There are thus produced two opposite effects, either an increase or a diminution of resistance, depending on the nature of the substance.

The effect of increase of contact-resistance is not an exceptional or isolated phenomenon, but is as normal and definite under varied conditions as the diminution of resistance noticed in the case of iron filings. These two specifically different effects have to be recognised, and it would be advisable, to avoid misunderstanding, to use a simple term to indicate both these effects, and distinguish them from one another, by calling the one positive and the other negative. The term "coherence" applied to the normal *diminution* of resistance exhibited by certain metals by the action of electric waves cannot be applied in all cases; for, as has been said before, there is another class of substances which exhibits under *normal* conditions an *increase* of resistance. The term "decoherence" has been used to indicate the effect of mechanical tapping, on fatigued substances of the former class; this produces an increase of resistance, and at the same time restores the sensitiveness. The action of tapping on fatigued specimens of the latter class is, however, a diminution of resistance.

I have shown in a former paper that the seat of sensitiveness is confined mainly to the surface layer of the sensitive substance, and that the nature of the substratum has little or no effect on the sensitiveness. Thus, a substance which exhibits a strong diminution of resistance, if coated with an extremely thin layer of a substance of the other class which shows an increase of resistance, will now exhibit an increase of resistance. It is seen that the re-action is one of the bounding layer or skin of the sensitive substance. There is a Sanskrit word, *twach*, which means the skin; and as the phenomenon dealt with in the present paper is one of sensitiveness of *twach*, I shall use the expression "electric *touch*" in the restricted sense of contact sensitiveness to electric stimulus, the touch being regarded as *positive* when electric oscillation produces an increase of conductivity or diminution of resistance, and *negative* when the contrary effect is produced. Substances which exhibit a decrease of resistance will be called positive, and those which show an increase will be regarded as negative. The above terms are to be regarded as convenient substitutes for long descriptive phrases.

The phenomenon of contact-sensitiveness seems at first to be extremely anomalous, and there appears to be little relation between substances which exhibit similar electric sensitiveness. Taking iron as an example of a very sensitive substance, it is seen to be easily oxidised, and from this it may be inferred that a slight oxidation on the surface is favourable for sensitiveness. This view obtains some support from the consideration that the so-called noble metals are not as sensitive as iron. But the metals nickel and cobalt, which are bright and not easily oxidised, are also highly sensitive. The very sensitive metals iron, nickel, and cobalt are all magnetic, and it might be thought that magnetic property is favourable for electric sensitiveness, but a diamagnetic substance like bismuth is also found to exhibit a fairly strong sensitiveness. Again, from the strong diminution of resistance exhibited by magnesium, it may be inferred that the sensitiveness depends on the electro-positive character of the metal; but potassium, one of the most electro-positive metals, exhibits the unusual increase of resistance.

There is one property, however, which at first would seem to be in some way related to the sensitiveness of metals—the volatility of metals under the cathodic stimulus, investigated by Sir William Crookes,* who gives the following list of metals, arranged according to their volatility:—

Palladium	108	Copper	40
Gold	100	Cadmium	31·99
Silver	80·68	Nickel	10·99
Lead	75·04	Indium	10·49
Tin	56·96	Iron	5·5
Brass	51·58	Magnesium	very slight
Platinum	44	Aluminium	

In this list the substances which are most volatile, *e.g.*, Pd, Au, Ag, are not very sensitive, whereas Fe, Al, Mg, which are least volatile, are strongly sensitive. But the above series does not exactly coincide with the series of electric sensitiveness. Again, the volatility of platinum is retarded in hydrogen gas, but an experiment carried out to determine the sensitiveness of platinum in hydrogen failed to show any great increase in the sensitiveness.

None of the above suppositions give any satisfactory explanation of the numerous anomalies in the contact-sensitiveness of metals. It then appeared that the observed effect is not due to a single cause but to many causes. An observer studying the dilatation of a gas under reduced pressure, and ignorant of the effect of temperature, will doubtless encounter many anomalies. In the phenomena of contact-sensitiveness the variables are, however, far more numerous, and the different possible combinations are practically unlimited. It therefore became necessary, by a long and tedious process of successive elimination, to find out the causes which are instrumental in producing the observed effect; the results obtained throw some light on this intricate subject. The following are some of the principal directions in which a systematic inquiry was carried out:

A. On the difference between mass action and molecular or atomic action, with reference to the phenomenon of contact-sensitiveness.

B. On the change of sign of response in a receiver due to a variation of radiation intensity.

C. On the physico-chemical changes produced in a sensitive substance by the action of electric radiation, and on the radiation-product.

D. The phenomena of electric reversal and of radio-molecular oscillation.

E. On "fatigue" and the action of mechanical tapping and other disturbances by which the sensitiveness of a fatigued receiver may be restored.

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* Crookes, 'Roy. Soc. Proc.', vol. 50.

F. On the relation between variation of electromotive force and resulting current through imperfect contacts.

G. On the systematic study of the contact-sensitiveness exhibited by metals, non-metals and metalloids.

H. On the contact-sensitiveness exhibited by alloys and compounds.

I intend to treat the above subjects in some detail, and in the present paper will especially deal with the first five lines of investigation. These, it is hoped, will afford an explanation of some of the most perplexing anomalies. All the subjects mentioned above are more or less interdependent, but their treatment in one paper would make the subject very complicated. It would be easier to take a more generalised and complete view of the subject as a whole, after each of the above-mentioned inquiries has been separately considered. With reference to the flow of electricity through imperfect contacts, I need only mention here that the phenomenon seldom obeys Ohm's law. There are in fact two characteristically different types, in the first of which the current is disproportionally increased under increased electromotive force; in the second we are presented with the astonishing result that the current is actually diminished under increasing electromotive force.

Mass Action and Molecular Action

Of the various attempts made to explain the action of contact-sensitiveness, Professor Lodge's theory of coherence has been the most suggestive. The coalescence of water and mercury drops in Lord Rayleigh's experiments, and Professor Lodge's observation of the welding of two metallic spheres by powerful oscillatory discharge in the neighbourhood, apparently lend much support to the theory of electric welding, which explains in a simple manner the diminution of contact-resistance of various metallic filings when subjected to strong electric variation.

On this theory it follows that *all* imperfect contacts should exhibit a diminution of resistance when subjected to electric radiation. In carrrying out a systematic investigation of the contact-sensitiveness of metals, I, however, found that there are substances, of which potassium may be taken as a type, which exhibit an increase of resistance. Potassium is not a solitary instance; I have found a large number of elements exhibiting this action; the number of compounds which exhibits a similar action is also considerable. Other experiments will be presently described which would show that the theory of coherence is inadequate. From the above it would appear that the subject is far more complex than was at first supposed. For various reasons it would be best to distinguish between two different classes of reaction, which may conveniently be described as mass action and molecular action.

Mass Action.—By this it is meant the general action, say, between two masses when placed in a very strong electric field. Under the given circumstance, sparking may take place between the bodies, and the two may thus be welded together. From what has been said it will be seen that such action is *non-discriminative*—that is to say, the action will be the same whatever the chemical or physical nature of the substance may be. The best way of showing this action is with drops of liquid, with surface contamination, for any incipient welding will be at once exhibited by the complete coalescence of the drops. The non-discriminative nature of the action is shown in a striking manner in the following experiment. I may mention here that fragments of solid potassium, and in a lesser degree sodium, exhibit an increase of contact-resistance under the action of electric waves. I made a liquid alloy of potassium and sodium, and drops of this alloy were allowed to float on the stratum separating dense Rangoon oil from lighter kerosene, the alloy being of an intermediate density. The drops coalesced when placed in an intense alternating electric field. The next experiment was made with potassium heated under melted (hard) paraffin. By stirring the molten K with a glass rod, the metal was broken up into numerous spherical drops. These also coalesced under similar electric influence. It is, however, to be borne in mind (1) that in the above experiment the substance is in the form of a liquid, and that in this particular condition certain important molecular changes, to be presently described, cannot very well take place; (2) that the conditions of the experiment are abnormal.

Experiments will be presently described which will show that the observed variation of conductivity produced by radiation is not due to coherence, but to certain molecular changes of an allotropic nature.

Molecular Action.—By this is meant the allotropic modification produced in a substance by the action of electric waves, the allotropic change being due to a difference in the atomic or molecular aggregation. It will be shown that such molecular change does take place by the action of electric waves, and that all the observed effects of variation of resistance of the sensitive substance may be explained on the theory of allotropic transformation due to the above cause. The effect due to molecular changes in a substance is also expected to be modified by the chemical nature of the substance; thus the molecular action due to radiation, giving rise ultimately to the variation of conductivity of the sensitive substance, will be *discriminative* in contradistinction to the non-discriminative mass action.

Is the effect of radiation due to non-discriminative coherer action or to the discriminative molecular action? That the effect is discriminative, and therefore molecular, appears to be decisively proved by the experiments described below. If further proofs are necessary they are afforded by the characteristic curves of variation of current with the E. M. F. given by the three types of substances, positive, negative, and neutral; by the continuity of radiation effect on matter; and, lastly, by certain remarkable results I obtained, which show that the effect of ether waves on elementary substances depends on the chemical nature of the substance; in other words, the effect is found to be a periodic function of the atomic weight of the substance. Detailed accounts of the above are for the present deferred for a future occasion.

On the Change of Sign of Response in the Receiver, due to a Variation of Intensity of Radiation

After finding the increase of resistance exhibited by certain substances, I wished to see whether these showed any further difference as compared to substances which exhibit a diminution of resistance. In my determination of the "Index of Refraction of Sulphur for the Electric Ray," I used the method of total reflection. I often noticed that just before total reflection, when the intensity of the transmitted beam became comparatively feeble, the receiver indicated an increase instead of the normal diminution of resistance. Professor Lodge mentions in one of his papers that an iron filing coherer exhibits an increase of resistance when acted on by feeble radiation. If the normal sign of response is reversed by a feeble intensity of stimulus, then negative substances may be expected to give a positive reaction with feeble radiation. Very sensitive substances are, however, not so well adapted for an exhibition of this reversed action possibly because the range of sensibility is comparatively great. But it is not difficult to demonstrate this property in the case of moderately sensitive substances.

The following experiment with a moderately negative substance (arsenic) and a moderately positive substance (osmium) will bring out this interesting peculiarity in a clear manner. The intensity of incident radiation may be varied in two ways; (1) by removing the radiator further and further from the receiver, or (2) by using polarised radiation, whose intensity may be varied by the rotation of an analyser. In the experiment to be described, the first method was adopted.

Experiments with Arsenic Receiver.—A receiver was made of freshly-powdered arsenic. The radiator used emitted radiation of strong intensity. It was at first placed close to the receiver, and there was produced a moderate increase of resistance. It was then removed further and further, and the increase of resistance became less and less. When the distance was increased to 25 cm. the action was reduced to zero; when this was further increased to 30 cm. there was a diminution of resistance, showing that 25 cm. is, in this case, the *critical* distance. The receiver continued to exhibit a diminution until the radiator was removed to a distance of 70 cm., when the radiation intensity was too feeble to affect the receiver. Now this critical distance may approximately be regarded as a measure of the sensibility of the substance. In this particular case the electric touch has a negative sign. If by any means (some of which will be described later on) the substance becomes more sensitive, *i.e.*, more negative, the critical distance will be increased. On the contrary, if the sensitiveness becomes less (the substance tending towards positive direction) the critical distance will be decreased. The application of this principle is of importance as affording a means of determining the variation of sensitiveness under different conditions.

Experiments with Osmium Receiver.—Substances which are feebly positive give a diminution of resistance when the radiator is close to the receiver, and an increase of resistance when the radiator is beyond the critical distance. Thus the critical distance for an osmium receiver (whose normal action is moderately positive) was found to be about 250 cm. At the reduced distance of 50 cm. the response was +150 divisions; this was diminished to +4 when the distance was increased to 200 cm. But at a distance of 300 cm. when the intensity of radiation was so feeble as to be below the critical, the response was reversed to —3 divisions.

In order to avoid confusion, we may choose to call the effect due to strong intensity of radiation as the normal action. The sign of normal action might further be verified, wherever possible, by obtaining a reverse action under feeble intensity of radiation.

Molecular Changes produced in Matter by the Action of Electric Waves

A sensitive receiver made, say, of iron powder, has its conductivity suddenly increased by the action of electric radiation ; but the sensitiveness of the receiver is lost after the first response, and it is necessary to tap it to restore the sensitiveness. On the theory of coherence, the loss of sensitiveness is explained by supposing that electric radiation brings the particles nearer and welds them together, and that the sensitiveness can then only be restored by the mechanical separation of the particles. This supposition, however, fails in the case of substances which exhibit an increase of resistance by the action of radiation. It may, however, be supposed that by some process, little understood, the particles are slightly separated by the action of electric waves, thus producing the observed increase of resistance. On this view, however, the restoration of sensitiveness by tapping remains unexplained. Again, if the increase of resistance is due to a slight separation of particles, suitable small increase of pressure ought to restore the original conductivity, as also the sensitiveness. It is, however, found that a considerable pressure is required to restore the original current, as if the outer layers of the particles were rendered partially non-conducting by radiation, and had to be broken through before the original current could be re-established. It is also found that though the sensitiveness is restored by this expedient of increasing the pressure, yet the restoration is only partial, and that after a repetition of this process the receiver loses its sensitiveness almost completely.

I have attempted to find out an explanation of this obscure " fatigue " effect. This subject will best be treated in connection with the anomalous behaviour of silver, which I find is also in a manner connected with the fatigue effect. Silver, when subjected to radiation, exhibits, as indicated in my last paper, sometimes an increase, and at other times a decrease, of resistance. The difficulty in this case cannot be explained on the supposition of variations of radiation intensity, as the anomaly persists even when the intensity of radiation is maintained uniform by keeping the radiator at a fixed distance.

In order to explain these actions, I assumed the following hypotheses, which, with the necessary deductions, are given below :—

(1) That electric radiation produces molecular change or allotropic modification in a substance.

(2) That, starting from the original molecular condition A, the effect of radiation is to convert it, to a more or less extent, into the allotropic modification B (the latter condition will be designated as the " radiation product "). It follows that this change from one state to the other must be accompanied by a corresponding change in the physical properties of the substance.

(3) As one of the properties of a substance is its electric conductivity, any allotropic change

produced by radiation should be capable of being detected by a variation in the conductivity of the substance.

(4) As a molecular strain is produced during transformation from A to B, at a certain stage there may be a rebound towards the original state A. Thus, after the molecular change from A to B condition has reached a maximum value, the further action of radiation may be to reconvert, to a more or less extent, B to A, this reversal of effect being indicated (see No. 3) by a corresponding electric reversal.

(5) That the ultimate loss of sensitiveness, known as " fatigue ", is due to the presence of the radiation product, or strained B variety, along with the A variety, the opposite effects produced by the two varieties neutralising each other.

The justification for the above hypotheses is to be sought for—

(1) From analogy with other known radiation phenomena.

(2) From experimental proof :

(*a*) Of the allotropic transformation being attended with changes in the conductivity of the substance.

(*b*) Of the existence (and, if possible, the production by chemical means) of an allotropic modification analogous to the radiation product or B variety, whose reaction should be opposite to that of the substance in a normal condition (A variety).

(*c*) Of the assumption that after the maximum transformation of A into B, the further action of radiation is to reconvert, to a more or less extent, the form B into A, such transformations giving rise to electric reversals.

(*d*) Of the existence of the radiation product in a fatigued specimen.

The above mentioned hypotheses will obtain still stronger support if further deductions from the above theory are borne out by confirmatory experiments.

I will now describe investigations on the lines sketched above.

Allotropic Modification produced by Visible Radiation

As regards the action of radiation in producing allotropic modification, several such instances are known in the case of visible radiation. In the familiar example, of the conversion of yellow phosphorus into the red variety, the effect is quite apparent. But this is not the case in the transformation of the soluble sulphur into an insoluble variety by the action of light ; here the transformation is not apparent, and has to be indirectly inferred from the insolubility of the solarised product in carbon bisulphide. The reason why a far larger number of instances of allotropic transformation produced by light is unknown, is not because such effects are not more numerous, but because we are unable to detect such minute changes. It must be admitted that our knowledge of molecular changes, specially in a solid, and the means of their detection, is at present extremely limited.

Variation of Conductivity produced by Allotropic Changes

There is one method of detecting these molecular variations to which little attention has hitherto been given, but which appears to be of great interest, and promises to yield important results in investigations of this class. It is evident that changes in molecular structure must be attended with changes of physical properties, electric conductivity being one of them. Among other instances of allotropic changes attended with changes in electric conductivity may be mentioned the wide difference of conducting power between graphite and diamond. The same great differences of conductivity is seen between the crystalline and amorphous varieties of silicon, and between the "metallic" and normal varieties of phosphorus. But it is not at all necessary to take only such extreme cases to show the influence of molecular or atomic aggregation in influencing the conductivity. This effect is brought into painful prominence by the variation produced, in spite of all precautions, in our standards of resistance.

Experimental Proof of Allotropic Changes being attended with variation of Conductivity.—I shall now describe a direct experiment by which the change of conductivity produced in a substance by molecular change is exhibited. Red mercuric iodide is converted into the yellow variety by the application of heat, and the substance does not return to its original state till after a considerable lapse of time. The recovery here is very slow. A small quantity of mercuric iodide was now placed in a tube provided with sliding electrodes, and a current was made to pass through the substance by

suitable compression. The conductivity of the substance is rather small, and therefore a thin stratum should be taken for experiment. The current is observed by means of a sensitive galvanometer. On the application of heat to the tube (which converts the red into the yellow variety), there was at once produced, simultaneously with the molecular transformation, an increase of conductivity. This effect is not due to a rise of temperature, for the increased conductivity was still exhibited on cooling the tube. From this experiment it is seen that the molecular changes can be inferred from changes in the conductivity. In the case described above, the recovery from the B, or second stage, to the first stage, A, is slow; but there may be substances (and there are such substances) where, under the given conditions of temperature and other physical surroundings, the first stage is far more stable than the second; the substance will then pass back quickly from the B condition to the primitive state, on the cessation of the exciting cause which gave rise to the transient B effect. The substance will in this case be "self-recovering."

Electrical Reversal in the Radiation Product

In the hypotheses given above, it was said that the reaction of the radiation product, or B variety, should be opposite to that of the substance in the normal condition, or in the A state. Thus a negative substance which by the action of radiation shows an increase of resistance during conversion from the A to the B state should exhibit a diminution of resistance when B variety is acted on by electric waves. The contrary would be the case with positive substances.

The following tabulated statement indicates the phenomena exhibited by two classes of substances :—

Sign of electric touch.	Action of radiation on the fresh or A variety of the substance.	Further action of radiation on the radiation product or B variety.
Positive, *e.g.*, iron .	Diminution of resistance.	Increase of resistance.
Negative, *e.g.*, arsenic	Increase of resistance	Diminution of resistance.

We have thus two distinct classes of phenomena dependent on the sign of electric touch. If K_A represents the conductivity of the fresh substance, and K_B the conductivity of the radiation product, then—

(1) With positive substances, as the conductivity of the radiation product is greater $(K_B>K_A)$, the first action of radiation would be to produce a diminution of resistance. This diminution will continue to be exhibited till the maximum amount of B variety is produced. The further action of radiation now will be to reconvert B into A; but as $K_A<K_B$ there would now be produced a diminution of conductivity, and a galvanometer in circuit will indicate an electrical reversal. The reconverted A variety may again be transformed to a greater or less extent to B, and in this way a series of reversals may take place, due to the continued action of radiation producing oscillation in molecular or atomic groupings. I shall designate this as the phenomenon of radio-molecular oscillation.

(2) With negative substances the conductivity of the radiation product is less $(K_B<K_A)$, and the first action of radiation will therefore be an increase of resistance. The phenomena exhibited by these negative substances will precisely be opposite to those shown by the positive substances.

The above is but an approximate representation of the phenomena. To be more accurate, one has to take into account the partial changes and the effect of radiation on these changed products. Thus, at first suppose the substance to be entirely made up of A variety (this would rarely be the case). The first flash of radiation converts a large portion of A into B, the substance now being a mixture of A and B. The action of the next flash would be to convert the unchanged A into B, and reconvert to a more or less extent B into A. The electric response will thus be very strong at the beginning, but will become continuously less and less. When the proportion of B has attained a maximum value, the reconversion of B into A will become relatively large, and thus give rise to reversal effect.

I spoke of the conversion "to a greater or less extent" of one variety into the other. There is also the question of the relative stability of the two varieties under the given conditions. From the above it will be seen what possibilities there are in the way of different combinations, and the varied phenomena, thereby rendered possible. I will presently describe some of the typical cases.

In the above it has been assumed that the reaction of B variety is opposite to that of A. As previously mentioned, in working with a silver receiver I found it, when fresh, exhibiting at first a diminution and, subsequently, an increase of resistance. The anomalous action may be explained by supposing the normal fresh silver Ag to be positive, and the radiation product Ag′ negative. These two varieties would thus give rise to opposite reactions. To justify the assumptions made above, it became necessary to obtain by some other means a variety of silver Ag′, analogous to the hypothetical negative variety.

Two Varieties of Silver

After many unsuccessful attempts, I at last obtained a variety of silver which gave a moderately negative reaction (increase of resistance). Silver chloride was first precipitated by the addition of dilute hydrochloric acid to silver nitrate solution. The precipitate was then reduced to metallic silver by zinc filings, the excess of zinc being dissolved off by the action of HCl. This form of silver gives a negative reaction. Direct precipitation of silver produced by dipping a piece of zinc in $AgNO_3$ solution gives a positive variety. The negative product Ag′ is perhaps better formed at relatively low temperatures, for the products obtained on certain warm days, the thermometer registering 27° C. were very feebly negative, and passed into the positive state after an interval of twenty-four hours. But on cold days (temperature=22° C.) the products obtained were stable. I have specimens which have kept the negative property unimpaired for nearly three months. The negative property is not due to any accidental impurity, for pure silver obtained by Stas' method also gave the negative reaction. The negative reaction may, however, be supposed to be due to a thin film of chloride formed during reduction. I washed the Ag′ with dilute ammonia, then with water, and, after drying, the result was still a negative reaction. I then carried out a parallel set of experiments with ordinary silver filings. Two separate quantities were taken; one was shaken with only HCl, the other was mixed with zinc filings, and the excess of zinc was dissolved off by HCl; the two specimens were then washed and dried. Both gave the positive reaction of ordinary silver. The above experiments are interesting for the production, by chemical means, of an allotropic variety analogous to the transitory radiation product.

There are other differences of electric behaviour between Ag and Ag′; for instance, when made into a voltaic cell, the two varieties give a P. D. of about 0·12 volt. There are several interesting peculiarities about this cell, the consideration of which is postponed to a future occasion.

Electric Reversal

It now remains to be proved that the "radiation product" exhibits a change of sign of electric touch. The sensitiveness of certain substances belonging to each of these two classes is very great, and the reversed action is likely to be masked by the stronger normal action of the still unconverted portion of the substance. It however occurred to me that if slightly sensitive substances were taken, then the direct and reversed actions were likely to be obtained with less difficulty. For this reason I took for my first experiments arsenic, which is moderately negative.

Observations with Arsenic Receiver.—Experiment I.—A receiver was made with freshly powdered arsenic ; the critical distance was found to be 25 cm. ; that is to say, when the radiator was moved from 1 to 25 cm. there was always produced an increase of resistance, while beyond this distance there was a diminution of resistance ; the critical distance, 25 cm., may therefore be taken as an approximate measure of the negative character of the specimen. As has been said before, if through any cause the substance becomes more negative, the critical distance will be increased ; but if the substance tends towards the positive direction by becoming less negative, then the critical distance will be decreased. The receiver was now continuously subjected to radiation for ten minutes. After this it was found that the receiver gave a diminution or positive reaction, even when the radiator was brought close to the receiver. The action of radiation has thus reversed the sign of electric touch.

Experiment II.—Any arbitrary length of exposure labours under the defect that what is observed is the final effect, the intermediate ones passing unnoticed. In order to observe the intermediate effects, a very laborious series of observations is necessary. The experiment was therefore modified in the following manner :—A fresh receiver was subjected to radiation, and observations at intervals of fifteen seconds were taken to test the nature of the reaction of the sensitive substance. The first action of radiation on the fresh specimen was a great increase of resistance, so very great that the current was reduced to zero ; it was no longer possible to make any further observation without re-establishing the current. This was done by a very gradual increase of pressure, effected by means of a fine micrometer screw which moved the compressing electrode in a perfectly parallel manner. There should be no jarring motion, as mechanical disturbance was found to break up the complex atomic aggregation in the radiation product. During eight minutes of exposure the receiver continued to exhibit an increase of resistance, after which the substance became positive, being converted to the B state ; this positive state lasted for a minute under exposure to radiation, then there was a reversal to the original negative state, as if the structure so laboriously built up suddenly gave way. Subsequently there were series of reversals, the specimen becoming more and more inert, and, after an exposure of about thirty minutes, the sensitiveness was practically lost.

The curve given below represents approximately the results of the experiment. During certain periods the substance became so nearly neutral that it was difficult to interpret whether the substance was positive or negative. The lower halves of the curve represent the negative and the upper halves the positive states, and the corresponding numbers represent, in minutes, the duration of these states.

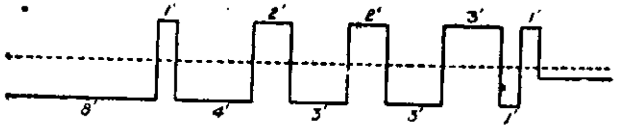

Fig. 23. Electric Reversal Curve.

Radio-molecular Oscillation

It was said that, owing to molecular reversals due to radiation, there should be a corresponding series of electric reversals. In this investigation it is essential that the substance examined should be completely protected from all disturbances, such as mechanical vibration and only subjected to the action of radiation. The experimental difficulties are very great. If we take a strongly sensitive positive substance—say iron, the effect of the first flash of radiation (a diminution of resistance) is very great, and the subsequent relatively feeble reversal effects, unless carefully looked for, are liable to pass unnoticed. After the first adjustment, the receiver should on no account be touched, as mechanical jars are found to undo the effect of radiation. Though by special care the mechanical jars could be reduced to a minimum, yet it appeared advisable to devise appropriate means by which the necessity of touching the receiver for subsequent adjustments is altogether avoided. The method adopted to this end varies with individual cases. In the case of arsenic, for example, the action of radiation is often to produce a very great increase of resistance, and thus convert the substance into a non-conductor. The pressure has therefore to be so adjusted at the beginning, that the substance can never become altogether non-conducting; the receiver is thus absolutely free from all effects, except those which are to be observed—*viz.*, the effects due to continuous action of radiation. The time of exposure is accurately measured by counting the individual flashes of radiation, due to interruption of the primary current in the Ruhmkorff coil by a tapping key. The conductivity of the substance at a given moment is inferred from the deflection of the galvanometer in circuit with the receiver. When feeble radiation is used, it takes an inconveniently long time to

obtain reversals; there is, besides, a tendency of self-recovery in the receiver. In order to expedite the reversals, the incident electric radiation is made very strong.

Before entering into the details of the results obtained, I will say a few words about the principal types likely to be met with. We may have the following :—

I. Substances in which the B state is unstable under the given conditions; the B state will therefore only persist during the action of radiation, the substance relapsing into the original condition on the cessation of radiation. Two cases are possible (i) when the substance is positive, (ii) when the substance is negative.

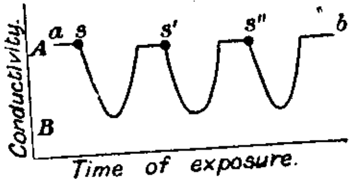

Fig. 24. Curve for Potassium.

The latter case is exemplified by potassium. In the above curve (fig. 24), A and B represent the two molecular states. The substance being negative, A is more conducting; *a* represents the conductivity of the fresh specimen; the thick dots S S′ . . . the individual flashes. It is seen that the effect of radiation is to produce a sudden diminution of conductivity, due to the transient formation of B variety with its diminished conductivity. The substance, electrically speaking, is highly elastic, and it exhibits automatic recovery on cessation of radiation. With the majority of substances, however, self-recovery is only possible when the narrow limit of elasticity is not exceeded.

II. In this class the radiation product is somewhat stable; the successive conversions from A to B and from B back to A are supposed to be complete. Probably there is no substance which exhibits this action in a perfect manner, but there is an approximation to this condition in the case of magnesium, which under proper adjustments shows successive complete reversals for a long time. The substance, however, after a time exhibits the effect of fatigue.

The curve given in fig. 25 clearly exhibits the reversals; it also explains the behaviour of magnesium noticed in my last paper, which appeared very curious at the time. " It is sometimes possible to so adjust matters that one flash of radiation produces a diminution of resistance, and the very next flash an increase of resistance. Thus a series of flashes may be made to produce alternate throws of the galvanometer needle."

The receiver was so adjusted as to give a deflection of five divisions. The first flash of radiation produced an increased deflection of 90 divisions (magnesium having a positive electric touch); the second flash produced a further deflection of five divisions, the third flash produced a *negative* deflection of five divisions, the fourth flash produced +5, the fifth flash gave —90 divisions, and the sixth flash a deflection of +90. The reversals followed each other almost regularly, till the substance became insensitive.

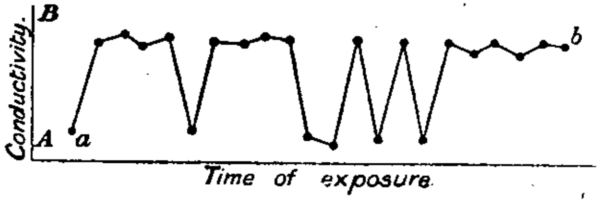

Fig. 25. Radio-molecular Oscillation Curve for Magnesium.

III. Lastly, there may be a class of substances where the conversion from one state to the other is not complete. Here, again, we get two sub-divisions, owing to the distinction between positive and negative substances.

Taking first the case of a positive substance (see fig. 26 (β)), the original conductivity of which is represented by *a*; the action of the first few flashes of radiation would be to produce a great increase of conductivity by the formation of B variety; the next flashes convert B back to A, but not completely, and the negative deflection will be less than the previous positive deflection. Owing to this " damping " effect, the oscillation curve will approximate to a logarithmic decrement curve. After a series of reversals the oscillation dies away, and the substance becomes almost inert. A glance at the hypothetical curve β shows that at the inert stage, *b*, *the substance as a whole is more conducting than in the fresh condition a* (see figs. 27, 28).

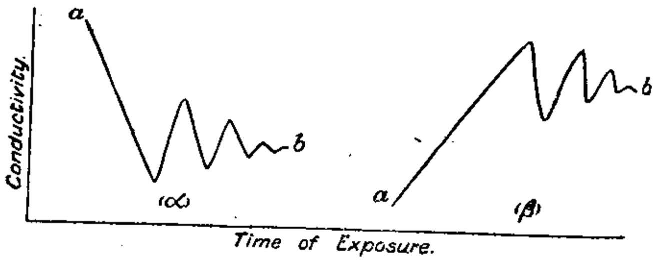

Fig. 26. " Damped " Molecular Oscillation.

The opposite should be the case with negative substances (fig. 26α).

Fig. 27 exhibits the actual curve obtained with a (compound) positive substance.

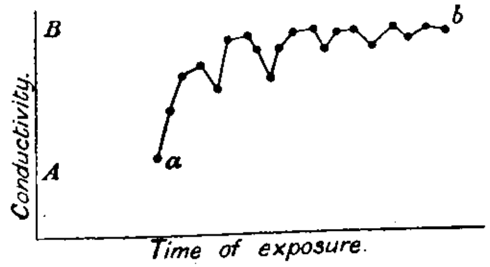

Fig. 27. "Damped" Oscillation Curve for a Positive Substance.

It is remarkable for its regularity. The next figure (fig. 28) gives the curve for iron. The first diminution of resistance is too great to be properly represented in the diagram. Here we have the same type as in the previous case; *the inert stage, b, is also more conducting than a;* (compare with fig. 26 β).

IV. I will now consider the case of a negative substance exhibiting damping; arsenic will be taken as an example where the damping is not so great as in the case of iron. Fig. 29 represents the actual curve obtained with arsenic (compare with the hypothetical curve for a negative substance, fig. 26α). It will be observed that *the negative substance in the fatigued state is, on the whole, less conducting than in the fresh condition,* as we were led to expect from the hypothetical curve.

It will also be seen that the oscillations are fairly regular towards the end. The curves given in figs. 28 and 29 are those obtained with specimens immediately after they were set up. Had I given them a period of rest to allow the particles to get properly settled, I would have got curves even more regular. It is, however, evident that in substances exhibiting

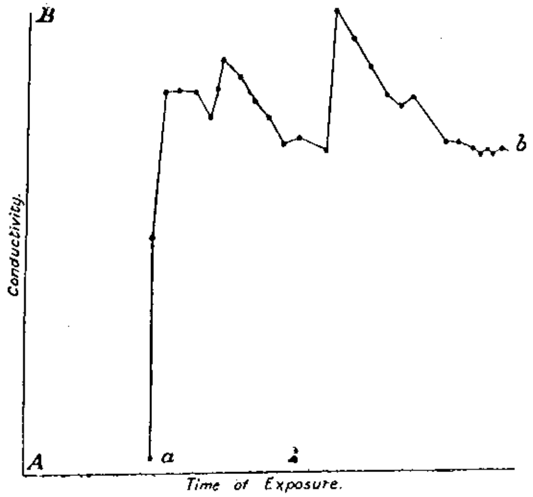

Fig. 28. Curve for Iron.

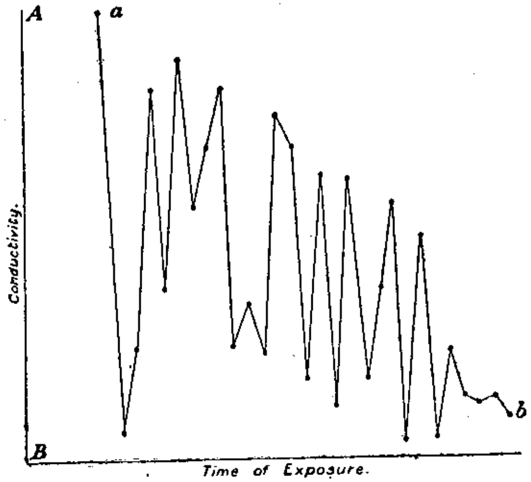

Fig. 29. Curve for Arsenic.

damping, two opposite electric effects are induced in fatigued specimens; the positive becomes on the whole more conducting and the negative less conducting than in the fresh condition. At the inert stage the rate of mutual conversion from one state to the other probably becomes equal, and the apparent fatigue is thus not due to the absolute want of sensitiveness of the constituent varieties, but to the opposite reactions of A and B balancing each other.

We may now apply some further crucial tests to verify the suppositions made above.

Restoration of Sensitiveness to a Fatigued Substance

It was said that the inertness of the substance, after long exposure, is due to the presence of a relatively large amount of strained B variety. It therefore follows that if by any means we can transform B into A, then after such a transformation there ought to be a restoration of the sensitiveness. It has also been stated that the B variety under ordinary circumstances is less stable than A. If now we apply a disturbing cause which is unilateral in its action—that is to say, if it converts B into A and not A into B—then such a disturbing cause will re-sensitise the fatigued substance.

Effect of Mechanical Disturbance.—Of the unilateral actions, mechanical vibration is one; for it is known that by the action of friction a substance may pass from one modification to another in one direction only. Thus the change of monoclinic into rhombic variety of sulphur is hastened by scratching with a glass rod, but the change does not take place in the opposite direction. We may now apply the crucial tests. Mechanical vibration will transform B into A, and with positive fatigued substances this should produce an *increase* of resistance (as A is less conducting than B); with negative substance the same disturbance ought to produce a *diminution* of resistance.

Effect of Heat.—There are other methods by which the B variety may be transformed into A; the more subtle molecular disturbance due to heat may be expected to be even more effective in producing the transformation. Here too, the crucial test is that by slight heating the fatigued positive substance ought to show an increase of resistance, and the negative substance a diminution of resistance. The two following curves (figs. 30 and 31) confirm my anticipations in a remarkable manner.

Effect of Heat and Mechanical Disturbance on a Positive Fatigued Substance.—I shall at first deal with the curve for iron. At the end of No. 28 curve, the substance was left in the inert stage *b*. While in this state, the receiver was heated to a slight extent. Observe in the dotted portion of the curve the sudden fall of conductivity (see fig. 30). I should state here, that, though the fall has been indicated by a straight line, as representing the somewhat sudden fall of conductivity, I sometimes noticed on careful inspection a slight oscillatory movement of the galvanometer spot during this process. The significance of this I will notice on a future occasion. The ultimate effect of slight heating (excess of heat produces other complications) is the restoration of the original reduced conductivity. If the application of heat transforms B into A, we may expect the substance to regain its sensitiveness, which it lost in the fatigued stage *b*. The receiver was now exposed to radiation, and it at once responded, exhibiting almost its original sensibility. Observe how the subsequent portion of the curve is a repetition of the curve No. 28, and how the substance arrives at the second fatigued state b'. To observe the effect of mechanical disturbance a gentle tap was given to the receiver, and at once there was produced an increase of resistance due to the transformation of B into A, the receiver regaining its sensitiveness by the transformation. The action of radiation was continued, and after a few reversals the substance once more arrived at the third fatigued state, b''. The process described above could be repeated any number of times.

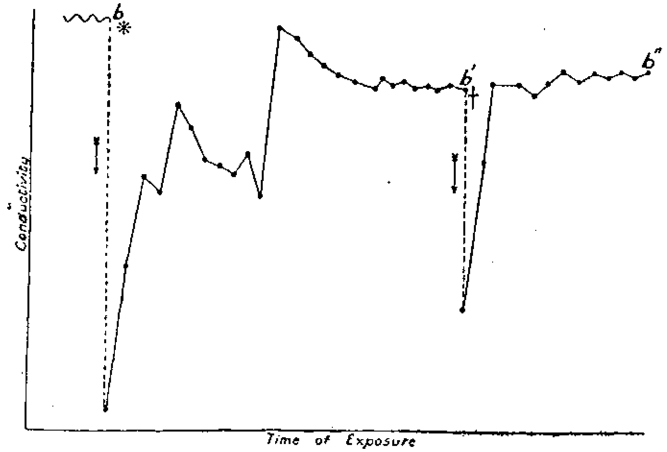

Fig. 30. Curve showing the Effect of Heat and Mechanical Vibration on a fatigued Iron-filings Receiver.

* Application of heat. † Application of a tap.

Effect of Heat and Mechanical Disturbance on a Negative Fatigued Substance

Experiments similar to the above were carried out with an arsenic receiver. From the curve given below (fig. 31) it is seen that the reaction of a negative substance is in every respect opposite to that of a positive substance. It will be noticed that in confirmation of theory, heating or tapping produces restoration of sensitiveness in the first class by an increase, and in the second by a decrease of resistance. I have been able to verify this deduction by observations with nearly a dozen different substances, and have not, so far, come across any to contradict it. It thus appears that tapping restores the sensitiveness not by the separation of the electrically-welded particles (in which case tapping ought to have produced an increase of resistance in *both* the classes of fatigued substance), but by removing the strain in B and thus converting it into A.

The effect of electric radiation is thus to produce re-arrangement of atoms and molecules in a substance; so does light produce new atomic and molecular aggregation in a photographic plate, a subject to be dealt with in detail in a future paper. Some of my audience at the Royal Institution (January, 1897) may remember

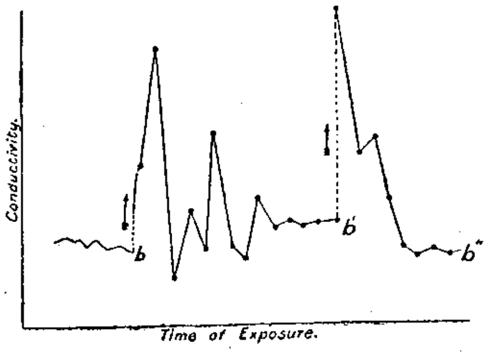

Fig. 31. Curve showing the Effect of Heat and Mechanical Vibration on a fatigued Arsenic Receiver.

b Effect of heat. b' Effect of tapping.

my attempt at explaining the action of the so-called coherers (which, perhaps, may be better described as "molecular receivers") by analogy with the photographic action. I had then no proofs for the assertion. I have since been able to obtain experimental evidence that the two phenomena are essentially similar. The coherer may therefore be regarded as a linear photographic plate; since we are more likely to understand the complex photographic action from the consideration of the much simpler action of electric radiation on elementary substances, where the effects are not complicated by secondary reactions, a photographic plate may be regarded as merely an assemblage of "molecular receivers." I hope also to prove that nearly all the detectors of radiation are molecular receivers in reality. The investigation of this aspect of the subject has given me some striking results; they seem to connect together many phenomena which at first sight do not seem to have anything in common. Another interesting question, the consideration of which has for the present to be postponed, is, Why is it that the sensitiveness is so marked in discontinuous metallic particles? In other words, Why is the phenomenon mainly one of skin or *touch*? Is the phenomenon wholly unknown in continuous solids?

The experiments described in the present paper show:—

(1) That ether waves produce molecular changes in matter.

(2) That the molecular or allotropic changes are attended with changes of electric conductivity, and this explains the action of the so-called coherers.

(3) That there are two classes of substances, positive and negative, which exhibit opposite variations of conductivity under the action of radiation.

(4) That the production of a particular allotropic modification depends on the intensity and duration of incident electric radiation.

(5) That the continuous action of radiation produces oscillatory changes in the molecular structure.

(6) That these periodic changes are evidenced by the corresponding electric reversals.

(7) That the "fatigue" is due to the presence of the "radiation product," or strained B variety.

(8) That by means of mechanical disturbance or heat, the strained product can be transformed into the normal form, the sensitiveness being thereby restored.

The method described above of detecting molecular changes is extraordinarily delicate, and is full of promise in many lines of inquiry in molecular physics. It is also seen that the phenomenon of contact sensitiveness, contrary to previous suppositions, is perfectly regular. There is no capriciousness in the response of sensitive substances to the external stimuli, which may be mechanical, thermal, or electric. The curves given above show this; but they fail to give a fair idea of the richness and variety of the molecular phenomena, seen as it were reflected in the fluttering galvanometer spot of light; of the transitory variations—of the curious molecular hesitation at critical times as to the choice of the structure to be adopted, and of the molecular inertia by which the newly-formed structure is carried beyond the position of stability, and the subsequent creeping back to the more stable position. The varieties of phenomena are unlimited, for we have in each substance to take account of the peculiarity of its chemical constitution, the nature of its response to ether waves, the lag and molecular viscosity. All these combined give to each substance its peculiar characteristic curve; it is not unlikely that these curves may afford much information as to the chemical nature and the physical condition of different substances. I am at present trying to arrange an apparatus which will, by means of the pulsating galvanometer spot of light, automatically record the various molecular transformations caused by the action of external forces.

(*Proc. Roy. Soc., Feb.* 1900.)

XIV

ON THE CONTINUITY OF EFFECT OF LIGHT AND ELECTRIC RADIATION ON MATTER

Though the theory of coherence gives a simple explanation of many cases of diminution of resistance in a mass of metallic particles subjected to electric radiation, yet there are other cases which cannot be explained by that theory. If coherence be due to electric welding, it would follow that *all* sensitive particles would exhibit a permanent diminution of resistance; in other words, the action should be non-discriminative and there should be no self-recovery. I have shown, however, in a previous paper, that the effect of radiation is by no means non-discriminative. On the contrary, while its effect on the positive class of substances, *e.g.*, Mg,Fe,Ni, is a diminution of resistance, its reaction on the negative class, *e.g.*, K,Ag′,Br,I, is precisely the opposite, namely an increase of resistance. Further, the conductivity change is not always permanent, since several substances are known which quickly recover and attain their original conductivity on the cessation of radiation, as if a force of restitution were called forth to restore them to their original condition.

I was thus led to suppose that the effect of radiation is to produce a state of molecular strain. Evidences will presently be adduced which will furnish proofs in support of this view.

If a substance is molecularly distorted by the action of an external agent, we may naturally expect that there would be produced changes in the physico-chemical property of the substance. As a familiar instance phosphorous is changed from the yellow to the red variety by the action of visible radiation. After the allotropic transformation into the red variety, phosphorus has become chemically less active, insoluble in CS_2, and of higher specific gravity. Similarly its other properties, such as its elasticity, its position in the voltaic series, its electric conductivity, etc., undergo a corresponding modification. An identical molecular phenomenon, seen from different aspects, may thus appear to be diverse. Looking from an electric point of view it is found that the conductivity of red phosphorus is greater than that of the yellow variety. It is thus possible to measure the induced molecular change by measuring the correlated variation of any of the properties described above. The choice of a particular method will be governed by special convenience under given conditions.

It would thus be possible to detect the effect of molecular strain induced by visible or invisible radiation by the following more or less sensitive methods. It is to be borne in mind that the effect of radiation is almost confined to the skin or outer layer of the substance.

(1) Method depending on the variation of the adhesive or cohesive power of a substance, *e.g.*, in a daguerreotype plate, the mercury vapour adheres by preference to the light-impressed portions only. Images may in a similar manner be developed by water vapour.

(2) Method depending on the variation of chemical activity undergone by the strained substance, or the method of photographic development. The acted and unacted portions are differently attacked by the developer. The action is not altogether independent of the effect described below.

(3) Method depending on the variation of electric potential, by which an E. M. F. is produced between the acted and unacted portions of a substance originally iso-electric.

(4) Method depending on the conductivity variation produced by the strain.

In the following investigations I shall employ specially the two last methods, and hope to demonstrate the fundamental unity of effects of visible and invisible radiation on matter. The subject is very extensive, and I propose to deal with it, as briefly as is compatible with clearness, in the three accompanying papers :—

I. " On the Continuity of Effect of Light and Electric Radiation on Matter." In this paper various experimental methods and results will be given, which can only be explained on the supposition that the observed effects are due to strain.

II. " On the Similarities between Mechanical and Radiation Strains." If the effects as described above are really due to strain, then similar results might be brought about by artificially producing strain in regard to which there can be no possibility of doubt, such as strain produced by mechanical means.

III. " On the Strain Theory of Photographic Action." Having shown the strain effect due to light, I will show how some of the obscure phenomena in photography receive a simple explanation on the above theory.

EFFECT OF ELECTRIC RADIATION

1. *Method of Conductivity Variation*

This method is specially suited for studying the effect of electric radiation on discontinuous particles. Since the action of radiation is one of surface, the larger is the superficial area the greater is the result; it is evident that loose particles expose a large surface to the incident radiation. Moreover, as the effective total resistance of the mass of particles is due to resistances of *surface* contacts, any change induced in the surface layers will cause great variation of the total resistance. In a continuous solid, on the other hand, only a comparatively thin molecular layer on the surface is acted upon; but this has little effect on the conductivity of the mass in the interior, protected by the outer conducting sheet. A slight conductivity variation can, however, be detected if the continuous solid takes the form of an extremely thin layer. I shall presently show that for the detection of molecular strain in a continuous solid the electromotive variation is the more suitable.

It has been stated that in the positive class there is produced a diminution, and in the negative an increase of resistance. These opposite reactions seem at first difficult to understand, but about their reality there can be no doubt. In another paper to be shortly communicated, I shall give an account of an independent inquiry in which the positive, the neutral, and the negative classes of substances are differentiated by their characteristic curves. From the strongly positive substance like Fe, Mg, to the pronounced negative like K, there are numerous gradations. In silver we have a material which is almost on the line of demarcation; it passes easily from one condition to another under the influence of external variations.

2. *External Change*

If the response, positive or negative, is really an expression of some changed molecular condition, we may expect it to be modified not only by the chemical nature of the substance, but also (1) by previous history of the substance, (2) by temperature, and (3) by pressure.

Influence of previous history.—As regards the first, I have already shown in a previous paper that a substance strained by radiation often exhibits opposite or reversal effects. Freshly powdered particles often show erratic results, but the effect becomes consistent after annealing, which also increases its sensibility evidently by increasing the molecular mobility. The improvement in sensitiveness often obtained by shaking of the particles is no doubt due to the same cause. In the various types of molecular receivers, whether responding to electric radiation, light, or mechanical vibration, similar effect is observed. The receiver generally speaking, improves gradually with working; but after long-continued action it gets overstrained and exhibits fatigue.

Influence of temperature.—As regards temperature, I have often found that on excessively cold days the receivers exhibit a diminution of sensibility, which becomes restored by warming. Various reactions which were very strongly exhibited in the warm climate of India, I found to be much diminished in Europe. Cautious application of heat often increases, not only the sensibility, but also the power of self-recovery.

High temperature, however, produces erratic behaviour by causing violent molecular disturbance.

Influence of pressure.—Pressure also has pronounced effect on molecular response. Moderate increase of pressure increases the sensibility, but too great an increase may cause a loss of sensibility. In substances which are nearly neutral, pressure variation may even cause reversal of response.

The same receiver may, owing to some obscure molecular modification, exhibit a response opposite in sign to the normal. But under continued stimulation of radiation, the abnormal response becomes converted into the normal. Parallel instances will also be noticed in the case of response to mechanical stimulus and to light. It is thus seen how the response is dependent on the molecular condition, and how a change of this condition may culminate in a reversal of response, say, from a diminution to an increase of resistance. The nature of the chemical substance, the molecular condition, the intensity and duration of radiation, the pressure, the temperature, and even the electromotive force acting on the circuit, are the factors instrumental in the determination of the resultant response. I have already shown how the cumulative action of continuous radiation may produce molecular reversal. There may thus be one or more reversals.

3. *Recording Apparatus*

In the following investigations, it is necessary to observe the conductivity or the electromotive variations, induced by external stimulus of various durations. It is also necessary to note the time-relations of direct and after-effects. The conductivity and electromotive variations can be deduced from the observed deflections of the galvanometer. When these are rapid, the observation requiring great alertness becomes very fatiguing. This difficulty is still greatly accentuated when simultaneous time-observations have to be taken. It thus becomes necessary to have at least two observers; the process of observation is very tedious, and the accumulation of results extremely slow. But in the apparatus now to be described, the mode of procedure has been very much simplified, affording facilities for quick and accurate record of responsive reactions.

The moving platform of the apparatus carries a squared paper (divided into $\frac{1}{10}$ inch) on which the record is made. The platform moves uniformly by clock-work, and the rate of travel of the paper may be roughly adjusted by means of different-sized pulleys, or more finely by the clock-work governor. The usual

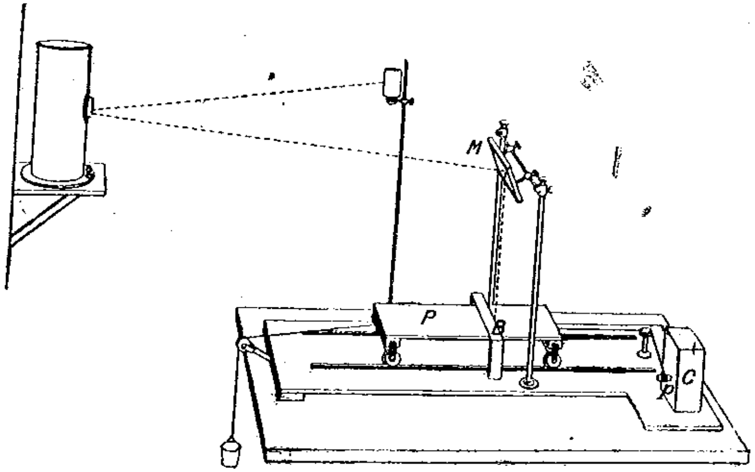

Fig. 32. The Recording Apparatus. P is the platform moving on rails and carrying the squared recording paper. C, the clock-work. M, the mirror to reflect the galvanometer spot of light on the platform.

rate is 1 inch in 30 seconds, and one small division of the paper measured horizontally is thus equal to 3 seconds. But very much quicker or slower rates may easily be obtained by means of the different-sized pulleys. The spot of light from the galvanometer is thrown down on the paper by an inclined mirror. The movement of the galvanometer spot takes place at right angles to the direction of motion of the paper. There is a guide rod at right angles to the motion of paper, along which the recording pencil is moved. The excursion of the galvanometer spot can thus be easily followed with a pencil, and it is quite easy to do this, when the fluctuation period is about 2 seconds. In the experiments to be described, this period varied from 2 seconds to several minutes. A curve is thus directly obtained, with conductivity or electromotive variation as ordinate, and the time as abscissa. The curves given in the accompanying papers are exact copies of the direct records.

4. *Transition of a Molecular Receiver from Non-recovering to Self-recovering Condition*

When a substance is strained by radiation there is produced a sudden variation of conductivity. The substance automatically recovers from the strained condition (1) if it has not been overstrained by an excessive stimulus, or (2) if its electric elasticity is very great. I have found, in general, that after careful adjustment of the receiver it exhibits tendency towards self-recovery, if the intensity of incident radiation is not too strong. In the case of substances which are, electrically speaking, highly elastic, such as K, there is an automatic recovery even after strong stimulation. The difference

exhibited by various substances in regard to self-recovery is one merely of degree. I give below typical cases which exhibit the gradual transition from so-called non-recovery to complete self-recovery.

The galvanometer used is a dead-beat D'Arsonval of moderate sensitiveness. The receiver was appropriately fixed on a heavy base. This was supported on one or two sets of pneumatic tyres so as to protect the sensitive receiver from mechanical vibration.

Positive Type.—In fig. 33 (*a*) is shown the effect of radiation on $Fe_3 O_4$ when cold. Only the upper portion of the curve is given; the flash of radiation produced a deflection of the galvanometer of sixty-four divisions.

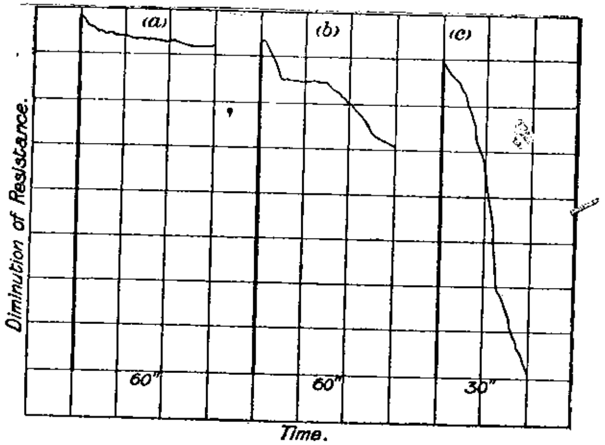

Fig. 33. Different stages in the evolution of a Molecular Receiver from a non-recovering to a self-recovering condition. The substance used is $Fe_3 O_4$, representing positive type, which exhibits a diminution of resistance under electric radiation. (*a*) the so-called non-recovery, really a case of very slow recovery; (*b*) the same slightly warmed, exhibiting a partial and arrested recovery; (*c*) the same with increased molecular mobility, recovery in 30″. In this and in the following, thick line represents response to radiation, thin line exhibits recovery.

It will be observed that it had recovered to the extent of three divisions in the course of 60 seconds; if the rate of recovery had been uniform, there would have been complete recovery in about 21 minutes, but in the later stages, the recovery is very slow. In (*b*) is shown the effect of increased molecular mobility due to cautious warming. There was now semi-recovery in 60 seconds; the quickness of recovery went on improving, and after a while the recovery was completed in 30 seconds.

Negative Type.—Fig. 34 exhibits the effect on the negative type as exemplified by Sn and Pb coated with Br. It appears that warmth is favourable to quick recovery; for in India with Pb coated with Br the self-recovery was obtained with the greatest ease. In the colder climate of England it takes a longer time for the receiver to become adjusted to the condition of self-recovery. At first the flash of radiation produces a sudden increase of resistance, from which there is no immediate recovery, but an inspection of the galvanometer spot at once makes it evident that some internal struggle has been going on; the spot trembles, as if to overcome some internal friction; the substance then exhibits a sudden recovery. After these preliminary molecular adjustments the recovery becomes perfectly automatic and instantaneous. Each flash of radiation then produces a responsive galvanometer twitch, *immediately* followed by recovery.

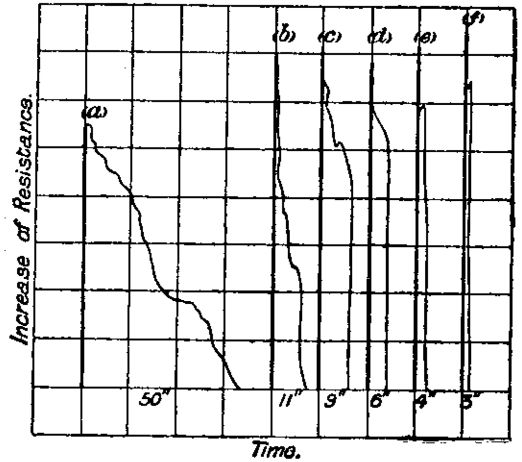

Fig. 34. Self-recovering Receiver exhibiting negative response (increase of resistance under radiation). (*a*), (*b*), (*c*), and (*d*) are the different stages of quickness of recovery in a brominated tin receiver; (*e*) and (*f*) are the records of a brominated lead receiver.

Some of the stages are well seen in the curves given. In (*a*) the recovery takes place in 50 seconds; in (*d*) in only 6 seconds; (*e*) and (*f*) show recovery in lead coated with bromine. The recovery gradually became very quick, from 4 seconds to 3 seconds; after that it was too quick for record.

In all the above cases it will be noted that the curve of recovery is convex to the abscissa; that is to say, it is at first very rapid, but in the later stage it becomes relatively slow.

5. *A Self-recovering and Metrical Receiver*

The most perfect type of self-recovering receiver that I succeeded in constructing was made of the strained variety of silver described in a previous paper. It was there shown that this variety of silver exhibits, under the action of radiation, an increase of resistance. I had with me a portion of this variety prepared more than a year ago, and it is probable that time had improved its quality. I made with it a receiver consisting of 3 mm. thickness of the powder between two electrodes; the pressure was adjusted by means of a micrometer screw which pressed one of the electrodes. The applied electromotive force was 0·4 volt, and the resistance of the receiver was equal to 20 ohms. The receiver showed the usual increase of resistance with a tendency to self-recovery. In about half an hour it began to exhibit the most perfect self-recovery, and for the next 3 hours of continuous work it went on giving an extraordinary consistency of response.

The intensity of incident radiation was varied by changing the distance of the radiator. In fig. 35 are given responses to individual flashes at distances of 40 and 15 cm. It will be seen that the effects are very consistent, the occasional variation being probably due to some of the oscillatory sparks not having been as efficient as the others.

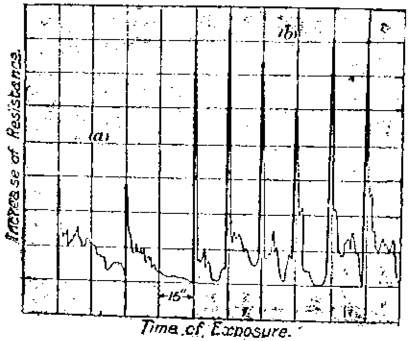

Fig. 35. Transient increase of resistance in an Ag′ receiver due to single flashes of radiation. In (*a*) the radiator was at a distance of 40 cm.; in (*b*) the distance was reduced to 15 cm. Thick lines represent the effect of radiation, thin lines represent the recovery.

Certain analogies with the phenomena of Phosphorescence and Thermo-luminescence.—A remarkable phenomenon will be noticed in the recovery curve. It will be seen that the complete recovery is effected after a series of minor oscillations. In other words, there seems to be an after-vibration which persists for a time in substances subjected to radiation. This is very suggestive in regard to a not altogether different after-effect of light in the fluorescent and phosphorescent bodies. In the case of Ag′ receiver, owing to its molecular mobility, the recovery is automatic. But in the case of so-called non-recovering substances, the strain persists for a considerable time; the recovery can, however, be hastened by removing molecular friction through gentle heating. In connection with this, I will quote an interesting observation previously made. In an iron receiver strained by radiation there was quick recovery after heating, and careful inspection showed a slight oscillatory movement of the galvanometer spot during the process. Here the strain produced by radiation remained latent to be released by heat. In the phenomenon of thermo-luminescence, the strain effect of light also remains latent till set free by the application of heat.

Effect of Continuous Radiation.—Still more interesting are the superposed effects of a series of flashes of radiation. The first flash produces a certain molecular distortion, attended with conductivity variation, from which it tends to recover. This force of restitution will be shown to increase with increasing distortion. Now if, before the substance has recovered from the first shock, a second flash be superposed, it will produce further distortion; but the effect will not be quite so strong, inasmuch as the force of restitution is increasing. Thus a series of superposed flashes will produce a limiting effect, which is kept balanced by the force of restitution. Under increased intensity of radiation, the balancing position is at a higher level. The after-effect, moreover, is more persistent under stronger intensity of stimulation.

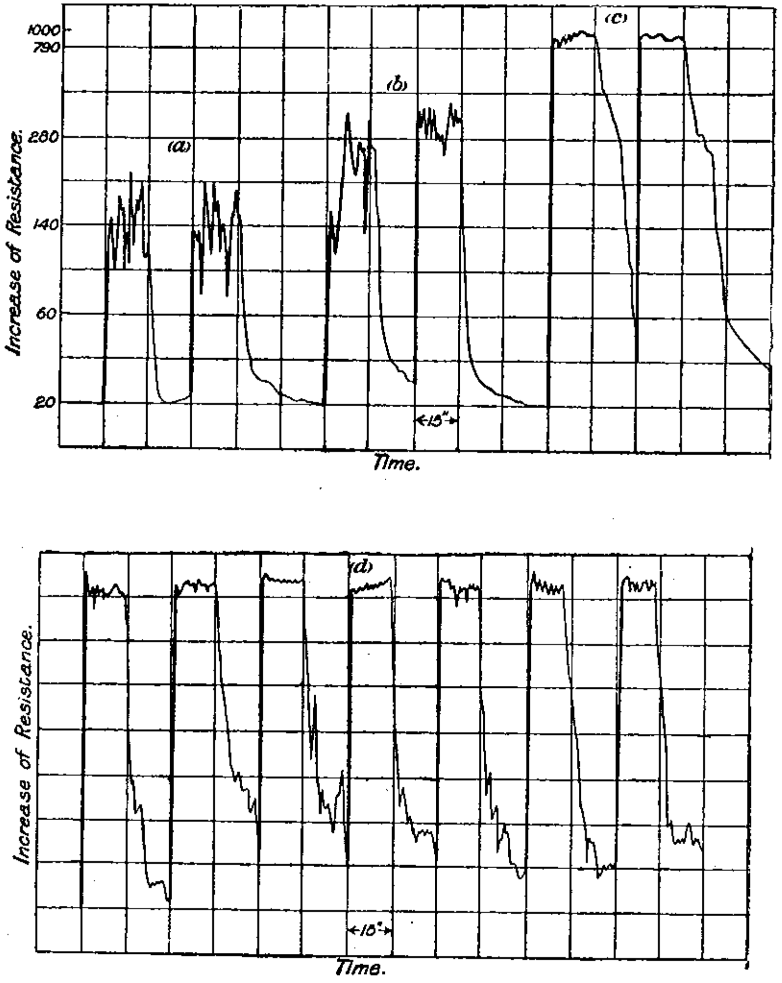

Fig. 36. Variation of resistance (deduced from diminution of galvanometer deflection) in Ag′ receiver produced by electric radiation lasting for 15″. Distance of radiator in (*a*)=40 cm.; in (*b*)=25 cm.; and in (*c*)=15 cm. In (*d*) is given a series of curves taken after half an hour with the radiator at a distance of 15 cm. The numbers on the left side of the upper curve indicate the absolute value of resistance.

In fig. 36 are shown the effects of rapidly succeeding flashes of radiation caused by the spring vibrator of a Ruhmkorff's coil. In (*a*) the radiator was kept at a distance of 40 cm.; the radiation was continued for 15 seconds, after which 15 seconds was allowed for recovery. A longer time would have allowed a more complete recovery, but this would have entailed a great loss of time in the long series of experiments contemplated. The recovery is therefore partial, the return curves not exactly reaching the original starting position. The record of response to the source of radiation at a distance of 40 cm. shows that there is a partial recovery between quickly recurring flashes, observed in the fluctuating response about the balanced position. Now when the intensity of radiation is increased by decreasing the distance of the radiator to 25 cm. (see *b*), the strain effect persists for a longer time, and the flashes arrive before the substance can have recovered to any extent; there is thus less fluctuation in the balanced position. The intensity of radiation was further increased by placing the radiator at a distance of 15 cm. (see *c*) the fluctuations now disappeared; and the galvanometer deflection was held rigid as long as the radiation was kept on; in fact, we have here an effect which physiologists describe as "tetanic." On the cessation of radiation there was an *immediate* recovery. It will be noticed how extraordinarily consistent are the succeeding values of response. The resultant effect being due to the additive effects of numerous flashes, an occasional failure of an individual flash is of little or no importance. The series of responses in (*d*) was taken after half an hour; it will be noticed how very consistent they are among themselves and how similar to those in (*c*), showing that even after half an hour's continuous work there had been but little fatigue with the attendant change of sensibility.

Relation between the Intensity of Radiation and the Conductivity-variation.—The resistance of the receiver being not very large, the external resistance of the shunted galvanometer and of the cell are not negligible in comparison; the change of deflections is, therefore, not proportional to the variation of resistance. To interpret the absolute values of the deflections, a resistance box was substituted for the receiver, keeping the rest of the circuit just as before. In this way the absolute values of the resistances corresponding to particular deflections were found. Some of these are given on the left-hand side of fig. 36.

The galvanometer deflections, when the radiator was at distances of 40, 25 and 15 cm., were 23, 33 and 42 divisions respectively. Owing to the comparative steadiness of the last two deflections there is no uncertainty about them; but on account of the fluctuation in the deflection when the radiator is at a distance of 40 cm., it is difficult to find the exact value of the deflection; the mean of the various deflections gives twenty-three divisions. The absolute values of resistances corresponding to these deflections are 180, 380, and 1020 ohms. The original resistance being 20 ohms, the *variations* due to the different radiation intensities are 160, 360, and 1000 ohms.

The intensities of radiation at the above distances may approximately be taken as proportional to $\frac{1}{40^2}$, $\frac{1}{25^2}$, $\frac{1}{15^2}$, or as 14 : 36 : 100. The corresponding molecular effects as measured by the increase of resistance are found to be as 16 : 36 : 100.

It will thus be seen how accurately the indications of the Ag′ receiver measure the intensity of radiation. Further progress in the study of different phenomena connected with electric radiation has been seriously hampered owing to the want of means for measurement of intensity of electric radiation. But this difficulty, as will be seen from the above, is not insuperable.

The strict proportionality of molecular effect can be taken as true only through a limited range. From the results of various experiments, into the detail of which I can not at present enter, it appears that, generally speaking, the curve of response (with molecular effects as ordinates, and the intensities of stimulus as abscissæ) is not a straight line. It is at first slightly convex, then straight, and in the last part concave. It is only in the second part that the curve is approximately straight.

In considering the effect of electric radiation in changing the conductivity of the particles, no explanation can be regarded as complete, unless it explains not only the diminution, but also the increase of resistance; the phenomenon of automatic recovery and the opposite effects exhibited by the same receiver under different molecular conditions, have also to be explained. The increase of resistance of the Ag′ receiver and its instantaneous recovery are directly opposed to the theory of coherence.

The state of balance between the effect induced by radiation and the force of restitution on the one hand, and the different equilibrium positions with different radiation intensities on the other, point to the phenomenon being due to molecular strain produced by radiation.

Fatigue of the Receiver.—I wished to trace the gradual appearance of fatigue in the Ag′ receiver, and for this purpose kept it acted on with slight intermissions for nearly 3 hours. At the end of that time it began to show unmistakable signs of fatigue. Fig. 37 shows the effect when the radiator was at a distance of 20 cm.; the deflections were now only twenty-one divisions, whereas before this the deflection was thirty-three divisions with the radiator at the increased distance of 25 cm. Formerly the recovery commenced immediately on the cessation of radiation, now there was a short period of hesitation and then it began to recover somewhat slowly. The extent of recovery also grew less and less, and at last the receiver suddenly exhibited the reversal effect, by showing a *diminution* of resistance.

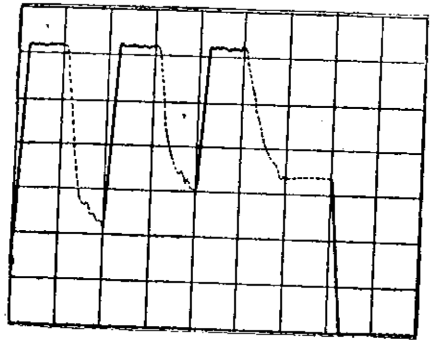

Fig. 37. Fatigue and reversal in the Ag′ receiver. Thick lines represent the effect of radiation, and dotted lines the recovery. Observe in the first three records the incomplete recovery and increasing fatigue. In the fourth, there is produced a reversal (a diminution of resistance instead of the normal increase).

A parallel instance under the continued action of light will be demonstrated later.

6. *Phenomenon of Reversal*

(a) *Effect of Sub-minimal Intensity of Stimulus.*—Another very curious phenomenon met with is the opposite effects of radiation below and above the critical intensity. I have in a previous paper shown that, whereas the effect of radiation of moderate intensity on As is to induce an *increase* of resistance, the effect of feeble intensity of stimulus is to produce a *diminution.* Positive classes of substances exhibit parallel results. The opposite effects of feeble and strong stimulation are exhibited not only under electric radiation, but also under mechanical stimulus (*cf.* p. 204). This result is certainly very curious, but I will show later on that exactly similar effects are produced under mechanical stimulation.

Possibly connected with the above is the following: A receiver subjected to radiation of moderate intensity, often exhibits a short-lived negative twitch immediately followed by the normal response. This is probably due to the fact that it takes some time for the sensitive substance to absorb the whole amount of incident radiation. The first moiety absorbed may thus fall below the critical intensity, and thus gives the preliminary twitch of opposite sign to the normal which occurs later by the absorption of a larger amount of radiation. The response-curve thus exhibits a negative twitch which precedes the normal.

(b) *Reversal due to Overstrain.*—I have also shown that overstrain due to the continued action of radiation gives rise to a reversal of response, the reversal being partial or complete. I give below a curve (fig. 38) for Fe_3O_4 under continuous radiation, where, after the maximum effect was reached, there was a distinct trend towards reversal.

The positive class of substances, the normal response of which is positive or diminution of resistance under moderate stimulation, gives negative response (increase of resistance) under sub-minimal stimulus. This is specially noticeable in a receiver rendered inert by prolonged rest. Annealing makes the response normal, as also previous stimulation. Strong and prolonged stimulation tends to reverse the normal negative response into positive. All these peculiarities of response under electric radiation will also be found characteristically exhibited by other receivers responding to the stimulus of light or of mechanical vibration.

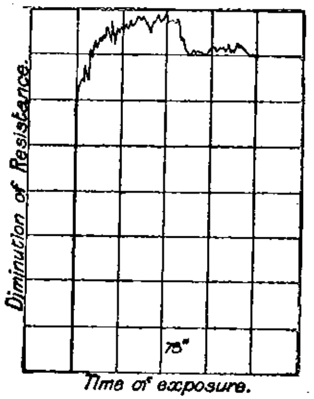

Fig. 38. Tendency towards reversal in Fe_3O_4 receiver under the continued action of radiation. Thick line shows the immediate effect, the thin line the continued effect of radiation. In other cases the reversal is complete.

7. *Physical Nature of the Change*

From the fact that the conductivity variation above described takes place in platinum and other noble metals, and the further fact that the action goes on even when the substance is kept immersed in a protecting medium such as naphtha, it would appear that the observed effect is primarily due to physical strain. By chemical action it is generally understood that the change is irreversible and in one direction. But in the cases of complete self-recovery exhibited by various substances, there is an automatic return to the original condition. It should, however, be borne in mind that, as a result of the strain, the chemical activity of the substance may undergo a change; a chemical action would occur if the strained substance be immersed in a medium for which it has a relatively stronger attraction.

8. *Electromotive Variation produced by Electric Radiation*

In consequence of molecular strain produced by electric radiation a difference of potential would likely be induced between the acted and unacted portions of a substance. A voltaic cell could be made with two plates of similar substance; there would then be no P. D. between the two. But on exposing one of the two plates to the effect of radiation, a difference of potential might be established between the acted and unacted plates. The differential effect, if it exists, could then be detected by a galvanometer or an electrometer. There are, however, many difficulties in rendering this method practical. First of all, in making a voltaic combination, some kind of electrolyte is necessary, but unfortunately all electrolytes are opaque to electric radiation. This difficulty could, however, be obviated to some extent by taking an electrolyte which is almost a non-conductor (*e.g.*, amylic alcohol) so as to be partially transparent to electric waves. The second difficulty is, however, far more serious for owing to the diffuse action of the comparatively long electric waves it is impossible to shield one plate while exposing the other. If both the plates are equally acted upon, there would then be no electromotive *variation*. It was only after the conclusion of another line of investigation on the electromotive variation produced by mechanical stimulus that a clue was obtained to overcome the difficulty. I then learnt that the effects of the same stimulus on two pieces of the same metal, forming a voltaic element, are not the same if the molecular conditions of the two are different. Under such a condition a P. D. exists between the two, and stimulation of both causes a variation of the existing electromotive force.

I therefore expected to detect the effect of electric radiation by an induced *variation* of the original electromotive force. And if the effects are at all parallel to those found in the conductivity variation method (as diminution or increase of resistance) the corresponding effects might be observed by a diminution or an increase of the existing electromotive force.

In carrying out experiments to verify the above suppositions, I found my anticipations to be justified. I at first made a cell by taking two varieties of silver. A piece of cotton wool moistened with amylic alcohol was placed in a glass tube. Ag and Ag′ were placed on opposite sides of the moistened cotton, thus forming a voltaic element, the amylic alcohol acting as the electrolyte. Two electrodes compressed the powder, till a current was observed to flow. As in the case of receivers for exhibition of conductivity variation, a careful adjustment of pressure is necessary for obtaining the best result. In order that the effect observed might be purely due to electromotive variation and not to the variation of conductivity, the cell was connected with a capillary electrometer. Owing to the opacity of the electrolyte the intensity of radiation has to be strong; the radiator was therefore placed at a distance of 6 inches from the cell. The incident radiation induced a responsive variation of the electromotive force. Long continued radiation induced a reversal as observed in the case of conductivity-variation previously described.

I give below the results of three experiments with different combinations :—

	Original E. M. F.	New value after the action of radiation.	Percentage reduction.
I . .	1·26 V.	1·15 V.	9
II . .	0·39 V.	0·312 V.	20
III . .	0·065 V.	0·039 V.	40

I was next desirous of obtaining a continuous record of electromotive changes induced by the continued action of electric radiation. For this purpose I used a galvanometer.

A cell was made, in the way previously described, with two specimens of magnesium powder. Owing to some differences in the two portions there was an initial P. D. of 0·042 V. between the two electrodes. The E. M. F. of the cell was balanced by the potentiometer method, a sensitive galvanometer (with an interposed high resistance) being used as the detector of electromotive variation. Fig. 39 (*a*) shows the deviation from the balanced position by radiation which nearly reduced the potential difference to half its original value. A second experiment [see (*b*)] gave almost identical results.

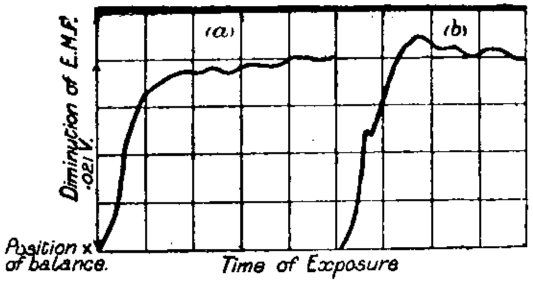

Fig. 39. E. M. variation in a Mg receiver. The original E. M. F. was 0·042 V. This was reduced to 0·021 V. by electric radiation.

It is thus seen that the response-curve by electromotive variation under electric radiation is similar to that obtained by the method of conductivity variation.

It has been shown that there is a recovery when the range of electric elasticity of the substance is not narrow, or when the strain is not too great; that on subjecting the substance to the continued action of radiation there is a limiting effect; that too long continued action tends to produce an electric reversal; that too feeble an intensity may give rise to a response of opposite sign to that of the normal. We shall next investigate whether visible radiation produces similar results.

EFFECT OF LIGHT

The molecular effect due to visible radiation may as in the previous case, be detected by the method of conductivity or electromotive variation. That light does produce conductivity variation is seen in selenium. I have also succeeded in detecting the effect of light in producing variation of contact resistance in a galena receiver. One and the same receiver responded in the same way when alternately acted on by visible and invisible (electric) radiation. The peculiarities of this universal radiometer were in every way similar to those of detectors for electric radiation.

It is, however, more satisfactory to study the effect of light in producing electromotive variation. Becquerel, Minchin, and others have shown that light produces an electromotive variation in a photo-electric cell. Like electric radiation, the effect of light is not confined to any particular metal or groups of metals, but all metals exhibit an electromotive variation under its action. Two opposite effects are likewise shown; in some cases the potential is raised, in others, the potential is lowered by the action of light.

I now proceed to show the remarkable similarity of the curves of response produced under electric radiation and under light. For the photo-electric cell I used two silver strips fastened by solid paraffin on two sides of a glass plate. The front surfaces were exposed to bromine vapour. The two strips formed the two plates of the photo-electric cell, the electrolyte being common tap-water.

If the two strips are exactly similar, then there is no P. D. between them, and the effect of light on either of the strips is the same. When both the plates are illuminated, there is then no resultant effect. But if the two plates are slightly different, then the effects on the two are not the same. An electromotive variation is induced even when both the plates are exposed to light.

9. *Effect of Short Exposure to Light*

In fig. 40 (*a*), is shown the effect of light of 2 seconds duration on one of the two AgBr plates. An incandescent gas-burner was placed at a distance of

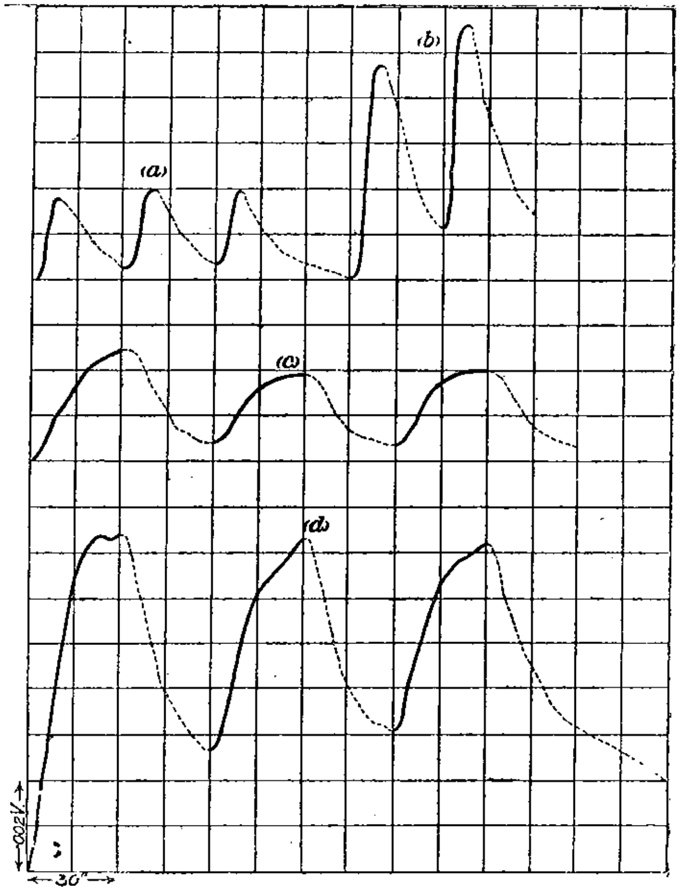

Fig. 40. Electromotive variation in AgBr cell due to the action of light. Ordinate represents E. M. variation, and abscissa the time. Thick lines represent the effect of light and dotted lines the recovery. (*a*) and (*b*) represent the effect of exposure to light for 2 seconds. The distance of source of light in (*a*)=12 inches; in (*b*)=6 inches. (*c*) and (*d*) represent the effect of continuous light for 30″; distance of source of light in (*c*)=18 inches; in (*d*)=9 inches.

12 inches. Previous maintenance of the plates in the dark enhances the sensitiveness; the cell then responds to feeble light emitted by a candle. The similarity of responses to light and electric radiation is very remarkable (*cf.* fig. 35). The recovery curve is also convex to the abscissa. The time allowed for recovery was not sufficient to bring the substance back to its original condition. The successive starting-points are therefore slightly ascending. In the last curve in the series (*a*) sufficiently long time was allowed, and the substance completely recovered in about 37 seconds. (*b*) shows the effect of light of about four times the intensity, the source being brought nearer to a distance of 6 inches. The effect is stronger, but not quite equal to four times the effect produced in the last case.

10. *Effect of continuous Action of Light*

Just as in the case of electric radiation, light produces a maximum effect, corresponding to a given intensity. Fig. 40 (*c*) shows the effect of continuous light of 30 seconds duration, the source of light being at a distance of 18 inches. Observe the tendency of the curve to become horizontal when reaching the maximum. (*d*) shows the effect of four times the intensity, the source of light being at a reduced distance of 9 inches. Here, too, the intensity of effect is not quite four times the effect of light at a distance of 18 inches.

11. *Reversal Effects*

With electric radiation it was found that the effect of a flash was sometimes a preliminary negative twitch immediately followed by the normal response. With light, too, it is frequently found, as has also been observed by Minchin, that the immediate result is a transitory negative followed by the normal action. A reversed response is also observed under molecular modification.

If the action of light is prolonged beyond the attainment of maximum effect, a tendency appears towards, or actual reversal.

In fig. 41 is given an interesting series of results showing the growth of fatigue, the different phases culminating in an actual reversal (compare with fig. 37). It will be seen that in the second, response was feebler, and a tendency towards reversal had already taken place after an exposure of about 9 seconds. In the third, the response is feebler still. In the fourth, the normal response lasting for 3 seconds, is extremely weak; there is then a reversal of response which is fairly strong. On the stoppage of light the reversed effect persists for some time. After the fourth, the responses become reversed.

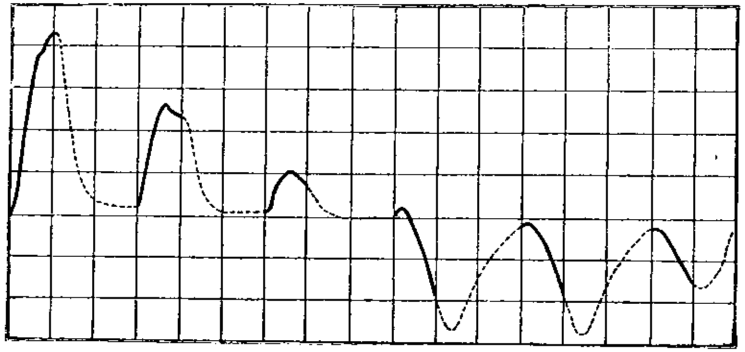

Fig. 41. Fatigue and reversal in AgBr cell.

It will thus be seen that both electric radiation and light produce similar conductivity and electromotive variations. Two opposite effects are observed in both. The response curves are similar in the two cases. Under the action of continued radiation both exhibit a limiting effect. Under too long continued action, both exhibit a tendency towards or an actual reversal.

(*Proc. Roy. Soc. June* 1901.)

XV

ON THE SIMILARITIES BETWEEN RADIATION AND MECHANICAL STRAINS

In the previous paper various effects have been described caused by visible and electric radiation. Considerations were adduced which tended to show that these effects were due to molecular strain induced in the substance by the action of radiation. The whole history of the change produced by radiation, both the direct and after-effects, were graphically recorded in the various curves. The strain effect produced in a substance was shown to be attended with conductivity or electromotive variation. We shall next inquire whether strain, which is undoubtedly produced by mechanical means, gives rise to response by conductivity and electromotive variations.

As regards the conductivity variation due to mechanical strain, it is well known that in the construction of standard resistance coils, winding the wire on a spool causes a distinct variation of resistance, and that this strain effect can only be removed by annealing. The difference between the resistance of a substance when strained and after it is annealed is sometimes very considerable.

The effect of electric radiation in changing the conductivity of a mass of discontinuous particles is very great. It is to be borne in mind that the effect of electric radiation is only skin-deep. As the action is one of surface, the larger the surface the greater is the effect produced. As already stated, the effective surface

accessible to radiation in loose particles is very much enlarged. Moreover, the resistance offered to the particles is not due to the individual solid lumps, but to the resistance of *surface* layer. It is precisely the surface layers that are affected by radiation, and hence the marked variation of resistance.

When the particles become continuous, the radiation can only affect the extremely thin layer of molecules on the surface, the mass in the interior being shielded by the outer conducting sheet; the molecular changes produced on the surface layer do not affect to any appreciable extent the conductivity of the mass.

For detection of strain effect in continuous solids the method of electromotive variation is the more suitable. It has been shown that light causes a P. D. between the acted and unacted plates. I shall next deal with the question whether mechanical stimulation gives rise to an electromotive variation between the acted and unacted plates.

1. *The Strain Cell*

For the purpose of the experiment, I made a voltaic element composed of two pieces WW′, taken from the same metal wire. These are fixed parallel to each other in an L-shaped piece of ebonite (fig. 42). The wires at their lower ends are fixed to the ebonite piece by means of ebonite screws SS′. The upper ends are fixed to metallic rods EE′ (which also serve as the electrodes), kept moderately stretched by springs CC′. The two electrodes lead to a sensitive dead-beat galvanometer of D'Arsonval type. A long handle, A, provided with a pointer, could be attached either to E or E′, and by its means either of the wires could be twisted. The angle of torsion is measured with the help of a graduated circle, not shown in the figure.

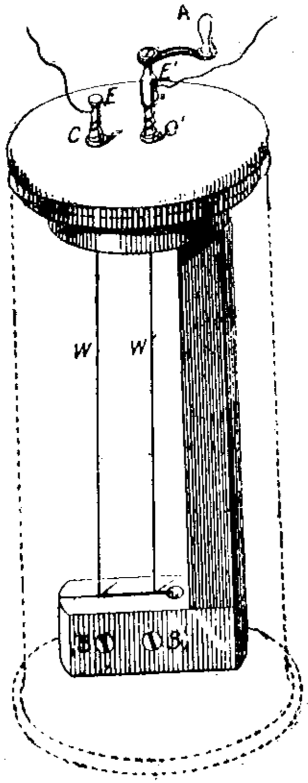

Fig. 42. The Strain Cell.

If a cell be made of two clean wires cut from the same piece, with water as the electrolyte there should theoretically be no P. D. between the two. But in practice a small P. D. exists between the wires, owing to slight difference in their molecular condition.

This initial difference can, however, be annulled by appropriate means, for example by subjecting them to mechanical vibration for a short time. After these precautions are taken, results are obtained which are extraordinarily consistent.

Now if one of the two wires be continuously twisted, an increasing P. D. is induced during torsion between the acted and the unacted wires. This may be measured by the deflection of the sensitive galvanometer. A curve of response could thus be obtained with electromotive force, measured by the galvanometer deflection, as ordinate, and the time during which disturbance is kept up as abscissa. Such curves were directly obtained by the recording apparatus described in my previous paper. The wire was twisted at a uniform rate. The successive dots represent the completion of 360°. To

keep the deflection within the scale, a megohm was interposed in the circuit. The resistance of the cell was about 5000 ohms. The absolute values of electromotive force corresponding to the galvanometer deflections were subsequently obtained by noting the effect of a known electromotive force.

2. *Effect of Torsional Disturbance*

Most of the metals—exceptions presently to be described—become negative during molecular disturbance caused by torsion, *i.e.*, the current through the *liquid* is from the acted to the unacted wire. As there is a considerable vagueness in the terms *positive* and *negative*, which has led to much confusion, I would name the acted wire as becoming *zincoid* or Z, when under an external disturbance the current flows *through the electrolyte from the acted to the unacted wire*. Again, in certain cases the reverse is true; the current flows from the unacted to the acted wire; the acted wire will in that case be designated as *cuproid* or C.

The induced electromotive variation is not due to twist as such, but to molecular disturbance induced during increasing twist. For if the wire be held stationary in the twisted position, the molecular disturbance with the attendant electromotive variation will gradually disappear (fig. 43). Other facts will be brought forward to show that the effect is due to the molecular disturbance.

The wires used in the following experiments were from commercial specimens. The length was in every case about 9 cm., but the diameters were not the same.

The responses under electric radiation, and under the stimulus of mechanical vibration will presently be shown to exhibit remarkable similarities. Still more extraordinary are the similarities that exist even in abnormalities, several instances of which will be given later; of these I shall mention here only one. It was shown in experiments with electric radiation that substances sometimes fall into a sluggish molecular condition, when the responses almost disappear. Strong stimulation (induction shocks, etc.) or annealing is then found to restore the sensitiveness. The same peculiarity is observed in the strain-cell. Lead, for example, specially on cold days, is apt to fall into a sluggish condition, when it becomes almost irresponsive. But it regains its sensitiveness after intense vibration or after annealing.

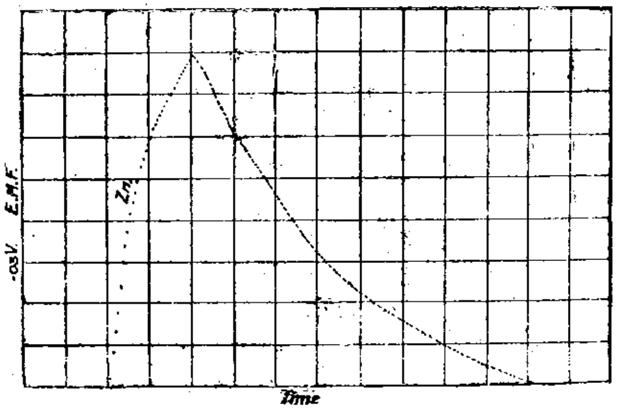

Fig. 43. E. M. variation due to torsion of zinc wire. Successive dots in the ascending portion of the curve represent effect of rotation through 360°. The descending curve represents recovery.

All metals (including the noble metal Pt) when molecularly disturbed exhibit electromotive effect. The intensity of electromotive variation depends on the nature and physical condition of the substance. The intensity of effect does not, however, depend on the chemical activity of the substance, for the electromotive variation in the relatively inactive tin is greater than that of zinc. The electrolyte used in the following experiments is common tap-water, but similar effects are also obtained with distilled water.

3. *Self-recovery*

It was said that the acted wire, usually speaking, becomes zincoid. This is not universally the case, for there are substances which become cuproid under mechanical stimulation. I have previously said that electric radiation produces opposite effects on different substances; silver is often found to show an effect (increase of resistance) opposite to that of generality of metals. It is very curious that silver is also often found to exhibit an opposite electromotive effect under mechanical stimulation, that is to say, the acted wire becomes C.

As long as the wire is not overstrained there is always a recovery. Observe the character of recovery in the curve for Zn when the twisting was stopped. It will be noticed that the recovery is very rapid at first, but slow in the later part, and that the recovery is complete.

4. *Irreversible Molecular Effect of Twist*

In the case of electric radiation or light, the impulses are of a vibrational nature, unlike the uni-directioned mechanical twist used in the above experiments. To make the two sets of phenomena comparable, we should have the mechanical disturbance of a vibrational nature also. I therefore next tried to see what the effect would be by reversing the direction of the twist, and found that the induced electromotive force is independent of the direction of twist, that is to say the electromotive variation is the same, whether the torsion is right-handed or left-handed.

I next tried the effect of a complete torsional vibration. I twisted the wire suddenly through +90°, then back to zero, then to—90°, and again back to zero, the complete vibration being executed in half a second. It will be seen that under these conditions we have a mere vibration and no resultant twist. This gives rise to an electromotive variation, the magnitude of which simply depended, as will be shown later, on the amplitude of vibration. It did not matter in the least whether the vibration commenced with a right- or left-handed twist.

It may be stated here that similar electromotive variation is obtained by molecular disturbance produced by a mechanical tap.

I shall now describe the effect of mechanical stimulus of varying intensities and durations. The intensity may be varied by varying the amplitude of vibration. We shall also study the effect of a single stimulus, or the summated effect of rapidly succeeding stimuli.

A set of experiments on the effect of mechanical stimulus may thus be carried out parallel to those on the effect of radiation stimulus. It would then be instructive to compare the response-curves of mechanical with those of radiation stimulus.

5. *Effect of a Single Stimulus*

For studying the effect of mechanical stimulus, a voltaic element made of " tin " wire* is very suitable. Normal responses are easily obtained after annealing.

As has been said before, any other metal may be used; I have, in fact, obtained as good results with platinum. But the advantage of tin is that the electromotive variation is comparatively strong; under favourable conditions this may be as high as 0·4 volt; another advantage is that it shows very little fatigue. On freshly making the cell, signs may be exhibited of abnormal irritability; this is due to the fact that a stable molecular condition has not yet been reached; but a more settled state soon supervenes, and after that successive responses are obtained which are extraordinarily regular and consistent amongst themselves.

That the response is due to molecular disturbance in the acted wire may be shown by the following experiment. The wire is clamped below; when the wire is subjected to torsional vibration, there is produced a strong molecular disturbance with the attendant electromotive variation. The wire is next released from the clamp and vibration imparted as before; there is now no electromotive response.

In fig. 44 is given a series of curves for different " intensities " of vibration. For want of space I have given a few only of each series. As a matter of fact, the succeeding series would have been mere repetitions of those which preceded. I have taken as many as 500 successive records, and each record is a mere duplicate of the rest. The substance does not exhibit any appreciable fatigue, especially if a period of rest be allowed for complete recovery. It will be seen that the rise is quick, whereas the fall is comparatively slow, specially in the later part.

With strain cells, there is no permanent change; the stimulated wire returns exactly to its original condition on the cessation of stimulus. In the border region between physics and chemistry no sharp line of demarcation can be drawn. In the case of tin cell the two wires are originally alike; under mechanical vibration a difference of potential is induced between the strained and unstrained wires. The induced electromotive variation disappears when the acted wire recovers from stimulation. We may describe the same fact in chemical language by saying that owing to molecular strain the stimulated wire becomes chemically more active (zinc-like), and that the wire recovers its original condition on the cessation of stimulus.

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* By tin wire is meant what is sold as such, and used as electric fuse. It is a pliable alloy of tin and lead.

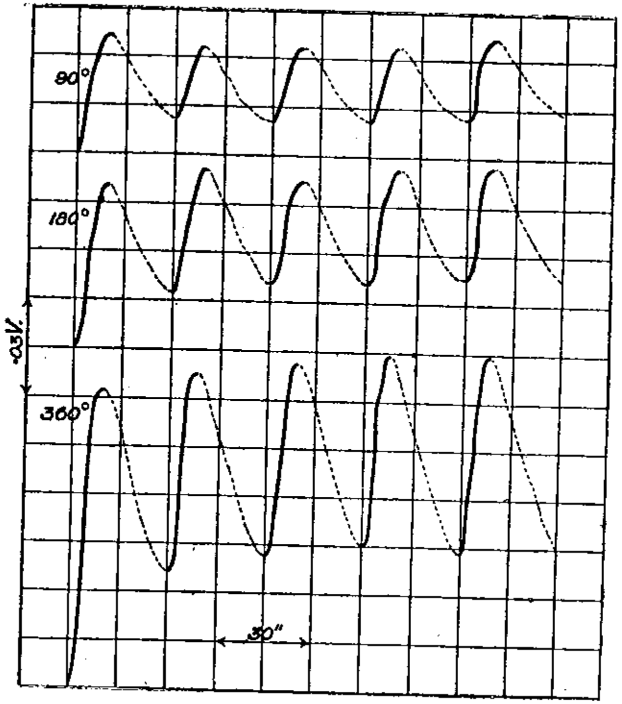

Fig. 44. E. M. variation due to a single vibration through 90°, 180°, and 360° in a Tin cell. Period of vibration 0·5″. Thick lines represent effect of stimulus, dotted lines represent the recovery.

6. *Increased Effect with Increasing Intensity of Vibration*

In fig. 44 are given the curves of response for single vibration, of amplitudes of 90°, 180° and 360°, the period lasting for 0·5 second. It will be noticed that the intensity of response increases with the energy of vibration.

7. *Effect of Summation of Stimuli*

In the case of effect of rapidly succeeding flashes of electric radiation on Ag′, it was shown (see fig. 36*d*) that the partial effects became fused together and that there was a limiting effect, kept balanced by the force of restitution. With rapidly succeeding mechanical stimuli, we again obtain precisely similar results. Fig. 45 (*a*, *b*) shows the effect of continuous vibration on tin cell, with different intensities of vibration, the vibration-frequency being twice in a second. The curve gradually rises and attains a maximum, at which position it is held almost rigid as long as the vibration is kept up. But on the stoppage of stimulation there is an immediate recovery, and if sufficient time be allowed the recovery is complete, as seen in the last curve of the series. The disturbance was kept up for 1 minute, and the period of recovery allowed was also 1 minute. In this way I obtained a long-continued series of similar responses, there being little fatigue; this is the case when a period of repose intervenes. But if the vibration is kept up without intermission, signs of fatigue begin to appear and the curve tends to fall. In some metals there may even be a reversal. Observe the flat top of the curve similar to that of Ag′ under electric stimulus mentioned above. Also the effects of different intensities of vibration, as shown in figure 45, (*a*) and (*b*).

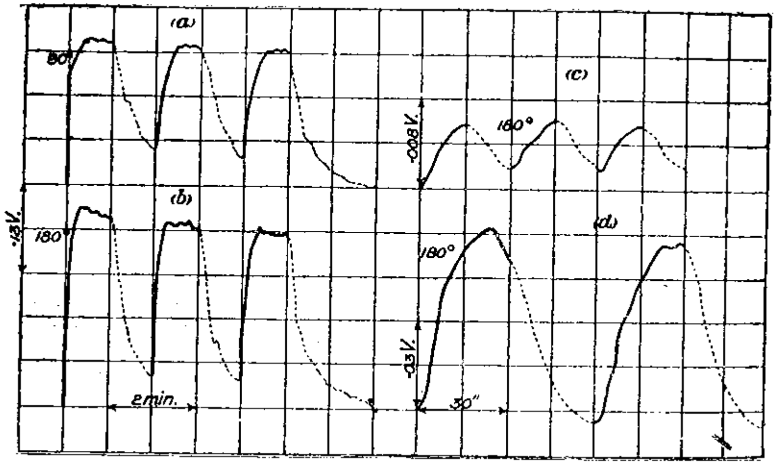

Fig. 45. Effect of continuous vibration. (*a*) and (*b*) show effects on a Tin cell. In (*c*) the effect on the particular Silver cell; the sign of E. M. variation is opposite to that of Tin cell. (*d*) shows the effect on a Nickel cell.

In (*d*) is shown the effect of vibration on Ni. After reaching the maximum there is a tendency towards reversal. Ni also shows greater signs of fatigue.

In (*c*), fig. 45, is shown the interesting curve for a given piece of Ag. The effect is very much feebler, and curiously enough it gave response of an opposite sign, the vibrated wire becoming cuproid. It was said that silver occupied a peculiar position as regards response to electric radiation, sometimes responding in one, and again in an opposite manner, probably owing to its readiness to pass from one molecular condition to another, under slightly different external conditions. With mechanical vibration, too, I find silver exhibiting positive or negative responses, the acted wire becoming on different occasions either Z or C.

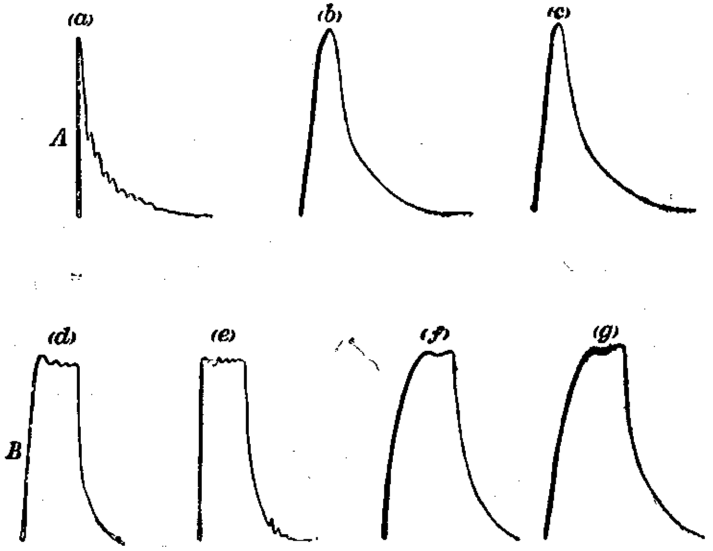

Fig. 46.

A. Effect of stimulus of short duration.
  (*a*) Effect of electric radiation on Ag′ (conductivity variation).
  (*b*) ,, light on AgBr (E. M. variation).
  (*c*) ,, mechanical vibration on Tin (E. M. variation).
B. Effect of continued action of stimulus.
  (*d*) Effect of continued action of electric radiation on Ag′ (conductivity variation).
  (*e*) ,, ,, ,, mechanical variation on Tin (E. M. variation).
  (*f*) ,, ,, ,, light on AgBr (E. M. variation).
  (*g*) ,, ,, ,, mechanical vibration on Nickel (E. M. variation).

8. *Reversal Effects*

Reversed Effect due to Sub-minimal Stimulus.—Just like the negative effect (*i.e.*, opposite to the normal) often exhibited under electric radiation when the stimulus is below the critical intensity, so also feeble mechanical stimulus often produces an effect opposite to the normal. Thus with strain cell made of lead.

I found that whereas the acted wire became cuproid with an amplitude of vibration of 4°, the same wire when vibrated through 45° became zincoid. Thus in a Pb cell (50,000 ohms in circuit):

Amplitude of vibration.	Deflection.	Result.
4°	5 divisions to right.	Acted wire C.
45°	70 ,, left.	,, Z.

The opposite effect under sub-minimal stimulus was too frequent to be accidental, but it did not occur invariably. On the occasions when it occurred, this negative effect disappeared after continued vibration. Thus on taking a record of effect of continued vibration, there is produced a negative twitch, which is converted later into a positive deflection, just as in the curves of effect of light (see below fig. 48).

Reversal produced by Continued Stimulation.—After the maximum effect the attainment of the further continuation of vibration tends to produce a reversal. This is specially the case with nickel in which the curve of response becomes completely reversed.

I have described the various molecular effects produced by mechanical stimulus under varying conditions, and shown how very similar they are even in details to the effects produced by electric radiation and light. How striking these similarities are will be seen from the following tabular statement and comparison of different curves.

9. *Response common to Electric Radiation, Light, and Mechanical Vibration*

1. The molecular effect produced may be detected either by conductivity or electromotive variation methods.

2. Substances when not overstrained exhibit recovery; the recovery is, however, delayed when there is overstrain.

3. Response is modified by previous history, and the influence of the surrounding conditions. Slight rise of temperature and annealing are generally favourable to increased sensitiveness and quick recovery.

4. Under the action of electric radiation, light, and mechanical vibration, two opposite effects are exhibited; by the conductivity variation method this is seen in the diminution or increase of resistance; a positive or negative variation is obtained by the method of electromotive variation.

5. In the curve of response, in all the above cases, the ascending portion is abrupt, whereas the fall during recovery is at first rapid, then comparatively slow, the curve of recovery being thus convex to the abscissa.

6. Under rapidly succeeding stimuli, there is a fusion of individual effects; the curve rises to a maximum, when the force of restitution is kept balanced by the force of molecular distortion.

7. Sub-minimal stimulus often produces a response of opposite sign to that of normal. Too long-continued stimulation produces, or tends to produce, a reversal.

8. Under certain molecular modifications, the response is of opposite sign to that of the normal. Continued stimulation converts the abnormal into normal. The response curve may thus exhibit, at the beginning, a negative twitch followed by the normal positive.

A number of curves selected from experiments already described, are given (see fig. 46) to illustrate graphically the remarkable similarities of response under diverse modes of stimulation.

10. *Effect of Stimulation by Light balanced by Mechanical Stimulation*

I have hitherto spoken of the similarities of the radiation and mechanical strains, but have not yet said anything about their mutual relation.

It is known that in cases where electric radiation produces an increase of conductivity, mechanical vibration produces an opposite effect, *i.e.*, an increase of resistance. It thus appeared that two opposite molecular effects were produced by the two different modes of stimulation.

In verification of this I investigated the effects of light and mechanical vibration in inducing electromotive variation in a strain cell. For this purpose I took a tin cell, and subjected one of the wires to the action of light and mechanical vibration alternately. The upper curve of fig. 47 shows the effect of light of a given intensity. It will be noticed that light makes the acted wire cuproid. But the action of mechanical vibration (see lower curve in same figure) makes the acted wire zincoid, and after several trials I found that a vibration with an amplitude of 3° produced a series of

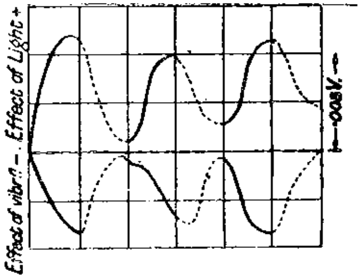

Fig. 47. Effect of light and torsional vibration on a Tin cell. Light makes the acted wire cuproid, mechanical vibration makes it zincoid.

curves similar, but of opposite sign, to those produced by light. Mechanical vibration thus produced a molecular effect opposite to that of light.

I next allowed both the stimuli to act simultaneously on one of the wires; the action of light was then found to be exactly balanced by the action of mechanical vibration, an increase or diminution of either at once upsetting the balance.

The molecular effect of mechanical vibration thus appears, at least in the case of tin, to be opposite to that produced by light. This may be the case in general; the exception might be when one of the two stimuli is normal and the other sub-minimal.

XVI

ON THE STRAIN THEORY OF PHOTOGRAPHIC ACTION

The uncertainty in regard to satisfactory explanation of photographic action is due to the experimental difficulties in studying the problem. As for instance :—

(1) There is reason to believe that every substance is molecularly affected by radiation, but detection of the induced change is rendered impossible by the imperfection of methods hitherto available, and also by the subsequent self-recovery of the substance in darkness. The effects can be detected in a few cases only when the changes produced happen to be visible, or become visible on development.

(2) As regards direct chemical tests, taking for example, the case of AgCl, the quantity of radiation product is exceedingly small; this occurs in the presence of a very large amount of unchanged chloride and the isolation of the minute traces of changed product is extremely difficult. Various secondary reactions, moreover, complicate the phenomenon.

To arrive at a correct idea of the changes produced, it is necessary to measure the minute effects produced by radiation on the extremely thin layer—perhaps only a few molecules deep—of the sensitive substance. In order to ascertain this, it is desirable to begin with the study of some elementary substance in which its effects are attended with few secondary complications. And, lastly, it is necessary to have some means of studying all the stages of change in a continuous manner, so that the important preliminary phase of " molecular negotiation " may not be missed. I have in my two previous papers shown how the above ideal requirements may be realised by taking advantage of the conductivity or electromotive variation methods which not only enable the detection of extremely minute molecular changes produced by radiation, but also to follow the changes moment after moment in a continuous manner.

I have described in the two previous papers the various molecular effects induced by light, electric radiation, and mechanical stimulation, under diverse conditions. The consideration of these will give a clear insight into various obscure phenomena connected with photographic action, among which may be mentioned the following :—

1. Photo-chemical induction.
2. Relapse of invisible image.
3. Recurrent reversals.
4. The development of pressure marks.

1. " *Chemical* " *and* " *Physical* " *Theories of Photographic Action*

It is an arbitrary distinction to call a phenomenon either physical or chemical when it happens to be on the common border region. I have shown that when a substance is molecularly strained by light, its chemical activity is modified in consequence of the physical strain. The acted and the unacted portions will therefore be unequally attacked by a developer. In the case of a compound, the strain produced by light may cause a modification which renders it susceptible to decomposition by the action of a reducing agent. The observed evolution of chlorine when moist AgCl is exposed to the long-continued action of intense light is often adduced in support of the chemical nature of photographic action. This extreme case of dissociation cannot, however, be regarded as representative of the action of light in the formation of latent images. In ordinary photographic action we have merely the effect of a moderate stress producing the corresponding strain (with concomitant variation of chemical activity), and not the disruptive effect of a breaking stress.

With reference to photographic action, various facts are known which cannot be satisfactorily explained by purely chemical considerations. In connection with this the following experiment of Professor Dewar is suggestive. It is found that at the low temperature of —180° C., there is a cessation of all chemical action. Even such an extremely active substance as K does not show any action when immersed in liquid oxygen.* Now at these extremely low temperatures, where the action of such an active substance as K is suspended, an Eastman film was still found fairly sensitive to photographic action.

In the above case, it is difficult to see how light could have produced any chemical action upon the relatively inactive silver salt. It is more likely that the effect produced was of the nature of some physical strain. That light does produce molecular strain even at such low temperatures—a strain which may remain latent—is shown from Professor Dewar's experiments on phosphorescence. Ammon. Pt. Cyanide cooled to

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* Dewar. Friday Evening Discourse at Royal Institution, June 26, 1891

—180° C. in liquid air absorbs light, but emits feeble radiation. But as the temperature is raised the stored-up light is emitted with very great intensity.

I now proceed to consider the photographic interpretations of the various molecular response curves taken under the action of radiation, as detailed in my previous papers.

2. *Substances may be Sensitive and yet give no Photographic Image*

The photographic effect on a sensitive plate is usually demonstrated by appropriate development, long after exposure. The after-effect of light on the sensitive substance may be fugitive or persistent. There are numerous gradations of this persistency of after-effect.

In order that the effect of light may be "developed," it is therefore necessary that the portions corresponding to the image should not in the meantime have recovered from the strain induced by radiation; for otherwise there would be nothing to distinguish the light-impressed portions from others not affected by light.

Though almost all substances are molecularly affected by radiation, yet there is a great difference in the permanence of after-effects. The recovery, as has been mentioned before, is very quick in some cases, whereas in others it may be protracted.

It is obvious that any method which attempts to develop the after-effect a long time after exposure will not be successful in cases where there is a quick self-recovery. It will only be successful where the strain effect is more or less persistent.

It is thus seen that it is quite possible for a substance to be sensitive to radiation, and yet seem to show no effect capable of photographic development, owing to rapid self-recovery.

3. *Relapse of the Invisible Image*

The above considerations afford a simple explanation of the very obscure phenomenon of the relapse of the invisible image. Recovery is merely a question of time. With certain substances it is immediate, with others it takes a longer time, as in a daguerreotype, where the latent image disappears in the course of several hours. In ordinary photographic plates the recovery may not take place for several years. We have seen how the strain effect of electric radiation was transient in some cases, whereas it was more persistent in others.

It is evident that in order to make the after-effect more or less permanent, and thus render it developable, self-recovery should be retarded. There are two ways in which the after-effect may be rendered comparatively permanent : (1) Even a highly elastic substance may be rendered more or less permanently distorted by straining it beyond the limit of elastic recovery ; or (2) the presence of a retarding substance may prevent the self-recovery of the sensitive material. One of the chief functions of the so-called sensitisers may pobably be in preventing self-recovery and rendering the after-effect permanent.

4. *Permanence of the After-effect by Overstrain*

Thus in many cases where images cannot be secured with ordinary exposure, they can be obtained with excessive strain caused by prolonged exposure. Thus Moser obtained an invisible image on a clean silver plate by exposing it to the sun for 2 hours or more. The invisible image was afterwards fixed by development with mercury vapour. A similar result was obtained with copper.

Major-General Waterhouse describes a very interesting series of investigations* in which by prolonging the exposure, printing-out impressions were obtained on silver. These could be developed not only by mercury or water vapour, but also by ferrous sulphate or pyrogallic developers. Images were also obtained on lead and gold.

These results derive an additional interest from the fact that most of the phenomena that occur by the exposure of ordinary photographic plates containing haloid compounds of silver can also be observed upon a silver plate exposed to light. In my experiments on molecular effects produced by electric waves, I found *all* metals sensitive to electric radiation, owing to the extremely sensitive method of conductivity variation. The molecular effects of visible radiation on various substances are also exhibited by the method of electromotive variation. In the experiments of Waterhouse, a considerable number of metals were found to be sensitive to visible radiation, the effect being rendered more or less permanent by overstrain.

5. *Electromotive Variation Curve due to Light*

I give below one out of several similar curves, showing the effect of continuous light on one of the two plates of a photo-electric cell of AgBr (fig. 48). In this curve several distinct stages are noticeable.

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* Waterhouse, 'Proc. Roy. Soc.' April, 1900.

(1) A short latent period, where there is apparently little or no action or even a transitory negative action. The curve given had to be contracted to put in all the different phases, and the peculiarities of the first part cannot therefore be very well shown.

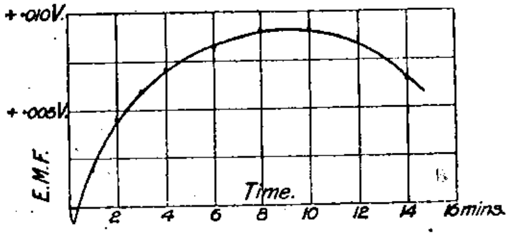

Fig. 48. E. M. variation curve for AgBr cell, under the continued action of light. Note the preliminary negative twitch.

I have previously remarked that in general the molecular strain curve is in the first part slightly convex, then straight, and in the last part concave; this is true not only under the action of stimulus of light, but also of mechanical vibration.

(2) In the second stage, the curve of response rises almost in a straight line, this being the phase of increasing action.

(3) The curve then reaches the maximum and becomes horizontal; after which it begins to fall thus exhibiting a reversal.

(4) During prolonged exposure the response-curve sometimes exhibits recurrent reversals.

The similarities of the molecular effects produced by light and by mechanical vibration have already been explained. The recurrent reversals are also occasionally obtained under mechanical vibration, as in the following electromotive variation curve for nickel (fig. 49), which was subjected for a long time to continuous mechanical vibration.

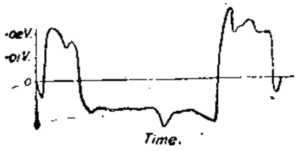

Fig. 49. Recurrent reversals obtained with a Ni-cell under continued vibration.

6. *Photo-chemical Induction*

The first part of the curve, or the latent period, is very suggestive as regards the obscure phenomenon of photo-electric induction. Thus "Quantitative measurements have shown that the action of light is not instantaneous. On the contrary, it gradually develops, and requires a considerable time before it attains its full strength. When a mixture of chlorine and hydrogen, which has been kept in the dark, is exposed to the light, there is either no hydrochloric acid or only a very small quantity formed in the first moment; but the rate of formation increases so that the quantity formed in a given time, *e.g.*, a minute, continues to increase until it attains a maximum value. Bunsen terms the gradual increase in the action *induction*. If the gaseous mixture has been once exposed to the light, it will retain in the dark, for about half an hour, its capacity for forming HCl in the light. If the gas has remained in the dark for a short period and is again brought into the light, it requires a very short period of induction; but the period of induction will be lengthened by keeping the mixture in the dark for a long time. [This is evidently due to self-recovery. J. C. B.] Exposure to the light renders the gaseous mixture capable of entering into combination, but it does not bring about combination itself."*

The latent period of the curve, due to molecular inertia, would thus appear to offer an explanation of induction. In connection with this it is interesting to note the well-known fact that a very slight preliminary exposure of the photographic plates considerably enhances their sensitiveness.

It would also appear from the inspection of the curve, that the general law of photo-chemical action, which regards the total action as proportional to the product of the light intensity multiplied by the time of exposure, is subject to several modifying conditions. During the latent period, this cannot hold good in the first part, nor can it be true after the maximum is reached. It can hold good only in the second stage where the action proceeds uniformly.

7. *The Effect of Intermittence in Modifying the Law of Photo-chemical Action*

But even after the substance has arrived at the second stage of uniform action, there may still be deviation from the above law. If in one case light be intermittent, and in the other continuous, the effects may be quite different, though the total durations be equal. For in the former case, during the continuation of light we may have distortion or molecular swing proceeding in a given direction, but on the stoppage of light, the swing stops too, sooner or later (sooner if the distortion has been considerable, when the force of restitution becomes great), and owing to self-recovery may even become reversed. After an interval, when the light is again

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* Meyer, 'Modern Theories of Chemistry,' p. 507.

allowed to act, it has not only to overcome the molecular inertia, but may have in certain cases to reverse the negative swing. In the case of continuous radiation, on the other hand, the molecular action proceeds without hindrance.

This is very well seen in the curve given below, which shows the difference in the extent of molecular effects produced in an AgBr cell by interrupted and continuous illuminations of the same total duration (fig. 50). Though light acted for the same length of time in both cases, yet in that of interrupted illumination the molecular effect as measured by the galvanometer deflection was only seven divisions, whereas with continuous illumination the deflection was 11·5, or one and a-half times as great.

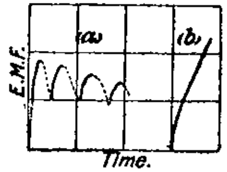

Fig. 50. Effect of (*a*) intermittent and (*b*) continuous illumination. In (*a*) there are four interrupted illuminations of 15″ each, the total duration being 1′. In (*b*) there was continuous illumination for 1′.

It is thus seen that owing to self-recovery, the effect of light with intermittent illumination is less. It is also evident that the greater the period allowed for self-recovery (during the interval of darkness) the less will be the resultant effect. In connection with this, the experiments of Abney are very interesting. In experimenting on the difference between the effects on photographic emulsion of a continuous exposure and a series of intermittent illuminations, he finds that in the latter gaseous mixture capable of entering into combination, but it does not bring about combination itself."*

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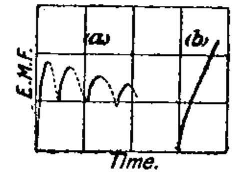

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* Meyer, 'Modern Theories of Chemistry,' p. 507.

8. *Photographic Effect Modified by Time-rate*

It will thus be seen that the photographic effect is not solely governed by the total amount of radiation, but by the time-rate also. The influence of this factor appears to be exhibited in the following cases. Cases (2) and (3) derive an additional interest from the fact that the effects are probably due not to absorption of radiation, as is usually the case in photography, but to the emission of radiation.

(1) In photographs of lightning, the line of discharge often comes out dark (the so-called dark lightning). It has been shown that reversals are produced by intense radiation ; we may thus have reversals of the first, second, and succeeding higher orders. Now it is possible that the reversal, or the dark-lightning effect, may be obtained, not only by a subsequent diffuse illumination (Clayden effect), but also by the action of lightning itself, provided that the intensity of illumination is sufficiently great and sudden to produce the reversal. The luminous intensity of lightning discharge is incomparably higher than any that can be produced by a spark from an electric machine. Mr. R. W. Wood* obtained reversal with a single spark, when the photographic lens was wide open, but there was no reversal with four sparks, the light aperture being reduced to one-fourth. The quantity of light was the same in the two cases, but the time-rate of illumination was different. This curious result would no longer appear anomalous, if we bear in mind the experiment in which the influence of time-rate was shown.

(2) In trying to obtain photographs by heat radiation on sensitised papers coated with a mixture of silver and mercury iodides, the following curious effect was observed. The sensitised paper was exposed to heat radiation and became uniformly reddish in colour. A mask with cut-out letters was now put on it, and the sensitised paper was allowed to cool. The rate of cooling was very rapid at the places exposed by the cut-out letters, whereas at the covered portions the rate of cooling was very much less. After a long time when the sensitive paper had cooled down to a uniform temperature, prints were still visible, the effect being evidently due to the different rates of emission of radiation in the screened and unscreened parts.

(3) Major-General Waterhouse mentions an anomalous case which seems to be explicable from considerations given above. He took a polished silvered glass plate, and put it into a printing frame with a cut-out paper mask and mica screen in which were cut-out initials, just as if it were going to be exposed to the sun ; but instead of exposure

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* 'Nature', November 30, 1899.

to light the plate was gently warmed for about 5 minutes over a spirit lamp, and then developed with mercury. The cut-out initials came out distinctly in dark lines. It would thus appear that since the plate was uniformly warmed, the difference between the screened and unscreened portions could only be in the different rates of emission.

9. *Phenomenon of Recurrent Reversals*

The fourth stage in the curve for the action of light will be found specially interesting with reference to photographic reversals, which are found to be recurrent. Thus, starting with a neutral condition, we obtain the first negative with a moderate exposure; longer exposure will tend to reduce the intensity of the negative and give rise to a neutral condition. Further exposure gives rise to a *positive*, then a second neutral, and again a succeeding negative, and this may be repeated in recurrent series.

Such recurrent reversals are also exhibited (see fig. 49) by a substance under continuous mechanical vibration. In my paper on "Electric Touch" I have given similar instances of reversals produced by the action of long-continued electric radiation.

10. *Other Methods of obtaining Latent Image*

If molecular strain be the basis of all photographic phenomena, then it ought to be possible to obtain latent images by other methods of producing molecular strain.

An instance of this is seen in the development of mechanical pressure marks. Images produced by electric strain are observed in the "inductoscripts."

11. *Conclusion*

It is thus seen—

(1) That molecular strain is produced by the action of light.

(2) That as the physico-chemical properties of a substance are changed by strain, it is possible to develop the latent image through the difference in the following properties between the exposed and unexposed portions produced by light.

  (*a*) Difference in adhesive power, *e.g.*, development of daguerreotype by mercury vapour, development by water vapour.

  (*b*) Difference in chemical stability, *e.g.*, development by reducing agents.

(3) That molecular strain may not only be produced by visible or invisible radiation, but also by (*a*) electric induction, and (*b*) by mechanical distortion. Latent images produced by such means may be developed, *e.g.*, inductoscripts, and pressure marks.

(4) That nearly all substances are sensitive to radiation, but the effect cannot in all cases be rendered visible, (*a*) owing to want of suitable chemical developers, (*b*) owing to quick self-recovery. The molecular effect due to radiation can, however, be demonstrated by the conductivity or electromotive variation methods.

(5) That the latent period of overcoming inertia corresponds to the photographic induction period.
(6) That the relapse of image is due to self-recovery.
(7) That owing to the tendency towards self-recovery the radiation effect does not solely depend on the total quantity of light, but depends also on the time-rate of illumination. Hence the photographic effects of intermittent and continuous illuminations, of equal total durations, are not the same.
(8) That the continuous action of radiation produces recurrent reversals.
(9) That the molecular effects produced by light and electric radiation are similar.

XVII

ON THE CHANGE OF CONDUCTIVITY OF METALLIC PARTICLES UNDER CYCLIC ELECTROMOTIVE VARIATION

A mass of conducting particles has its conductivity changed when subjected to rapid electric vibration, as for instance, when acted on by electric waves. I have, in previous papers, adduced reasons leading to the conclusion that electric radiation produces a molecular change, and that conductivity variation is the expression of the induced change. We know that the physical properties of a given substance depend on its molecular condition. Any molecular change that may be induced may therefore be expected to be attended by changes in the physical properties of the substance, electric conductivity being one of these. The wide difference in electric conductivity of the same substance under different molecular conditions is seen in the case of carbon, in its two allotropic forms of graphite and diamond. The effectiveness of radiation in producing allotropic changes is seen in the conversion of the yellow into the red variety of phosphorus under the action of light.

That the variation of conductivity induced by electric radiation is due to some atomic or molecular action is seen from the fact that it is dependent on the chemical nature and the molecular condition of the substance. Thus, under electric radiation, the positive class of substances, *e.g.*, Fe, Mg, etc., exhibit an increase of conductivity, whereas the negative class of substances, *e.g.*, K, Br, I, show a diminution. The effect of molecular conditions in determining the sign of response to electric radiation (*i.e.*, increase or diminution of conductivity) is exhibited by the two molecular varieties of silver, the response being positive in one case and negative in the other.

The conductivity variation is thus the expression of some molecular change. In many cases (potassium, Ag, brominated lead, etc.) we find that the change persists only during the action of radiation. On the cessation of the stimulus the substance at once shows elastic self-recovery. It would thus appear that the conductivity variation is due to molecular strain produced by radiation. This view is further supported by the fact that in working with self-recovering receivers of various types, both positive and negative, I have not only found that for each intensity of radiation there is a corresponding conductivity variation, but that under the continued action of radiation, the conductivity variation attains a maximum value, which remains constant, balanced by a force of restitution; when the radiation is stopped, the subtance is found to recover its original conductivity. With an increase of intensity of radiation, the corresponding conductivity variation also increases, and *vice versa*. I have, in a Paper "On the Continuity of Effect of Light and Electric Radiation on Matter" given an account of self-recovering receiver, of negative type, made of silver particles, in which the conductivity variation is almost exactly proportional to the intensity of radiation. Self-recovery, in general, is merely a question of time; with certain substances it takes place immediately, with others, after a short or after a comparatively long period. This view of conductivity variation, as the expression of some molecular change, will receive independent support from the experiments on a self-recovering receiver to be described later.

The conductivity changes take place not only under very rapid Hertzian oscillations, but also under much slower electromotive variations. Thus an electromotive variation, whether quick or slow, is the effective cause of induced change of conductivity. In substances which exhibit recovery from the action of radiation so protracted, as to appear practically non-recovering, the induced molecular change is attended by a more or less permanent variation of conductivity. Recovery in such cases can be hastened by molecular vibration, by mechanical taps, or by the application of gentle heat.

After a rapid cyclic variation of E. M. F. the substance is thus transformed from its primitive condition; in other words a more or less irreversible molecular change is induced at the end of the process as exhibited by a hysteresis of conductivity. If this view be correct, then we can study the molecular change step by step, by observing the conductivity variations undergone by the substance as it is carried through a complete cycle of electromotive variation. The rapidity of this process must be just sufficiently slow to allow the successive changes to be recorded. The suddenness of electric variation no doubt exerts an influence on the amount of change; but this is a question of degree only.

The investigation thus resolves itself into the determination of the variation of conductivity of the sensitive particles, as the mass is subjected (1) to a continuously increasing E. M. F. from zero to a maximum, and then (2) to a continuously diminishing E. M. F. from the maximum back to zero. The required information may be obtained by the interpretation of the characteristic curve, in which the abscissæ represent the impressed E. M. F., and the ordinates give the corresponding values of the current. A continuously increasing E. M. F. can be made to act on the sensitive substance, by the movement of a slider over a potentiometer wire, say, to the right. The scale readings of the potentiometer give the values of the E. M. F. The readings of the galvanometer in circuit give the corresponding values of the current ; movement of the slider to the left produces a continuous diminution of E. M. F. The characteristic curve can thus be obtained from the observed values of E. M. F. and the corresponding currents.

This is a bare outline of the principle of the investigation described in this Paper. Various experimental modifications have to be introduced in order to overcome certain difficulties and render the method practical.

Before entering upon the subject of experimental arrangements, I may repeat what I pointed out in my paper on Electric Touch that in regard to their response to electric radiation, there are three types of substances, positive, negative and neutral, differentiated " by the characteristic curves of variation of current with E. M. F." The positive exhibits an increase of conductivity ; the negative shows a diminution of conductivity ; and the neutral does not exhibit any conductivity change. The first two of these classes again fall into two subdivisions, of substances which exhibit self-recovery and those which do not. The characteristic

curves of the three classes of substances thus belong to three distinct types, so that it is possible to determine the class to which the sensitive substance belongs by its characteristic curve.

These curves also throw much light on the obscure subject of the action of radiation on various sensitive substances. In the present Paper I shall describe in some detail the reaction of the first class of substances. *i.e.*, those which show a diminution of resistance, and amongst these I shall take typical instances of non-recovering and self-recovering substances, and demonstrate the peculiarities of their cyclic characteristic curves. A brief reference will also be made of the characteristics of the second class which exhibit an increase of resistance.

Experimental Arrangements

The electric circuit consists of (1) the sensitive substance, (2) a sensitive dead-beat D'Arsonval galvanometer, and (3) a potentiometer arrangement for a gradual and continuous increase or diminution of E. M. F.

1. *The Sensitive Substance.*—Experiments were made with both single and multiple contacts. In the former case the pressure of contact was adjusted by means of a fine micrometer screw, or by means of springs. In some cases the contact ends were both rounded ; in others, a pointed end pressed against a flat piece.

In the case of multiple contacts, a small quantity of metallic filings was put in a glass tube, and the fragments compressed between two electrodes, the pressure being regulated by a perfectly easy-running micrometer screw. The pressure was adjusted till a feeble initial current flowed through the circuit. The micrometer screw, together with the tube of filings, were appropriately fixed on a heavy base. This rested in turn on a steady pedestal, with one or two sets of pneumatic tyres interposed. Experiments were carried out with the sensitive substance in air, or immersed in kerosine.

2. *The Galvanometer* was appropriately shunted so as to give a deflection of one division of scale for a definite small fraction of an ampere. In some experiments, for example, one division of the scale was equal to 10^{-6} ampere. The calculation of resistance of the sensitive substance is very much facilitated if the scale values of the galvanometer and the potentiometer were suitably adjusted beforehand. The resistance of the shunted galvanometer and the potentiometer was practically negligible in comparison with the resistance of the sensitive substance, which usually varied from about 1,000 to 50,000 ohms.

3. *The Potentiometer* consisted of a thin nickeline wire of uniform section, 20in. in length. Each inch of the scale was further sub-divided into tenths. A storage cell with an interposed resistance was applied to the terminals of the potentiometer, and the resistance adjusted till the terminal E. M. F. attained a suitable value. This was found by the help of an auxiliary voltmeter applied to the terminals of the potentiometer.

The E. M. F. acting on the main circuit was derived from the potentiometer; one end of the circuit was connected with one terminal of the potentiometer and the other connected with a slider, the movement of which to the right or to the left increased or diminished the impressed E. M. F. The sliding contact was made by means of a bent flat metallic spring which uniformly pressed against the potentiometer wire. Care was taken to maintain a uniformly good electrical contact. Any sudden introduction of the E. M. F. was avoided with special care, as, owing to the self-induction of the circuit, an unknown induced E. M. F. might act on the sensitive substance. The slide-contact was therefore never broken; starting from zero of the scale (E. M. F.=0) the slider was moved at a uniform rate to the right, thus continuously increasing the E. M. F. without any sudden variation. Movement of the slider to the left produced a continuous diminution of E. M. F. The voltaic cell was never cut off from action till the slider returned to zero.

Method of Observation

One observer moved the slider at a uniform rate and called out the successive potentiometer readings; the corresponding deflections of the galvanometer were read off by the second observer, and a third took down in parallel columns the applied E. M. F. and the corresponding galvanometer readings. From these data the characteristic curves could be subsequently obtained. This method of work was, however, very tedious. It took a long time and the co-operation of three persons to complete one experiment, and the curves could only be obtained from a series of observations which were not absolutely continuous. I had, therefore, to devise a recording apparatus by which a continuous curve could be obtained in a simple and direct manner.

Recorder of Conductivity Variation

If a platform be fixed to the slider of the potentiometer, then the movement of the platform in one direction would continuously increase the E. M. F. acting on the circuit containing the sensitive substance (fig. 51). If the galvanometer spot of light is thrown down on the platform by a mirror, suitably inclined, and if

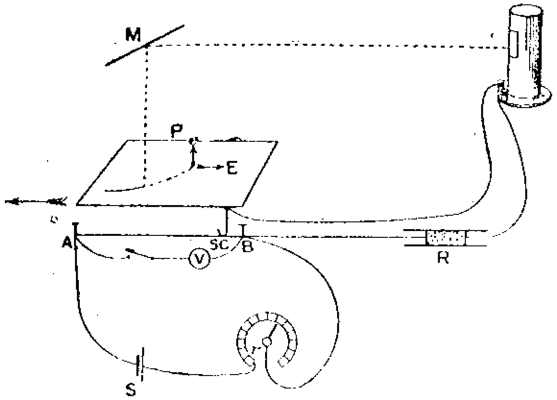

Fig. 51. Diagrammatic Representation of Conductivity Recorder.
P, Moving Platform. AB, Potentiometer. R, Sensitive Receiver. r, Rheostat
V, Voltmeter. SC, Sliding Contact. S, Secondary Cell. M, Mirror.

the movement of the spot of light, due to variation of current, takes place at right angles to the motion of platform, then a continuous curve would be traced on the platform, of which the abscissæ would represent the E. M. F. and the ordinates the currents. This curve could be fixed if we laid a sheet of photographic paper on the platform, or we might obtain it by the simpler expedient of following the track of the galvanometer spot with a pencil.

I used squared paper for recording the curves. It is divided into inches, and these further sub-divided into tenths. The potentiometer wire is 20in. long, and the length of the platform is the same. As the platform moves through its own length past a fixed index, the sliding contact moves through the whole length of the potentiometer. If the applied E. M. F. at the terminals A and B be, for example, 1 volt, each inch of paper along the platform would then represent $\frac{1}{20}$th or 0·05 volt, the smaller sub-division representing 0·005 volt. This or any other suitable terminal value of E. M. F. can be obtained with the help of the storage cell S, a rheostat *r* and an auxiliary voltmeter V, applied to the terminals A and B.

The galvanometer, as was said before, is also adjusted by means of a shunt, so that a deflection of one division is a convenient small fraction of an ampere. The absolute values of the E. M. F. and current being known, the resistance of the sensitive substance at any point of the curve can easily be determined.

In the completed apparatus the platform is mounted on small wheels and moves on rails with perfect smoothness. A string connected with one end of the platform is carried round a large winding wheel and a second string connected with the other end of the platform carries a counterpoise. When the wheel is turned at a uniform rate in one direction, the platform carrying the paper also moves at a uniform rate, at the same time producing a continuous increase of E. M. F. acting on the circuit. When the wheel is turned in the opposite direction, the counterpoise reverses the motion, and the impressed E. M. F. undergoes a continuous diminution. In this way it is possible to produce either an increase, or a decrease, or a rapid cyclic variation of E. M. F. I shall first describe in detail the rising part of the curve thus obtained, and then deal with peculiarities of complete curve when carried through a cycle.

Characteristic Curve of a Single Point Iron Receiver

In order to reduce the conditions of experiment to their simplest, I first studied the effect of E. M. variation on contact at a *single* point. The change induced was thus confined to the molecular layers at the point of contact. This consisted of a sharp point of iron, pressing against a convex iron surface, the pressure being capable of very delicate adjustment by means of a micrometer. Five different experiments were carried out with the same receiver.

The initial adjustments were made with an E. M. F. of 0·05 volt. The only difference made in the several experiments is as regards the initial current, caused by change in the pressure of contact.

In curve A (fig. 52) the initial current was the lowest value of the series. The pressure of contact was adjusted till the initial current at 0·05 volt was $2/10^5$ ampere. The E. M. F. was now continuously increased by the turning of the winding wheel, and the curve obtained in the manner previously described.

It will be seen that the curve is not straight, but concave to the axis representing the current. As the E. M. F. is increased, the current increases at a greater ratio. I may say here, in anticipation, that this appears to be a characteristic of the positive class of substances, *i.e.*, of those which, like iron, exhibit a diminution of resistance under electric radiation.

The resistance of the receiver is thus not constant, but undergoes a *continuous* decrease with increasing E. M. F. The conductivity is therefore increased with the rise of E. M. F. The curve becomes steeper as the E. M. F. is increased, the conductivity undergoing a rapid and continuous increase.

Hence conduction in such cases does not obey Ohm's law. The resistance is not independent of the E. M. F.

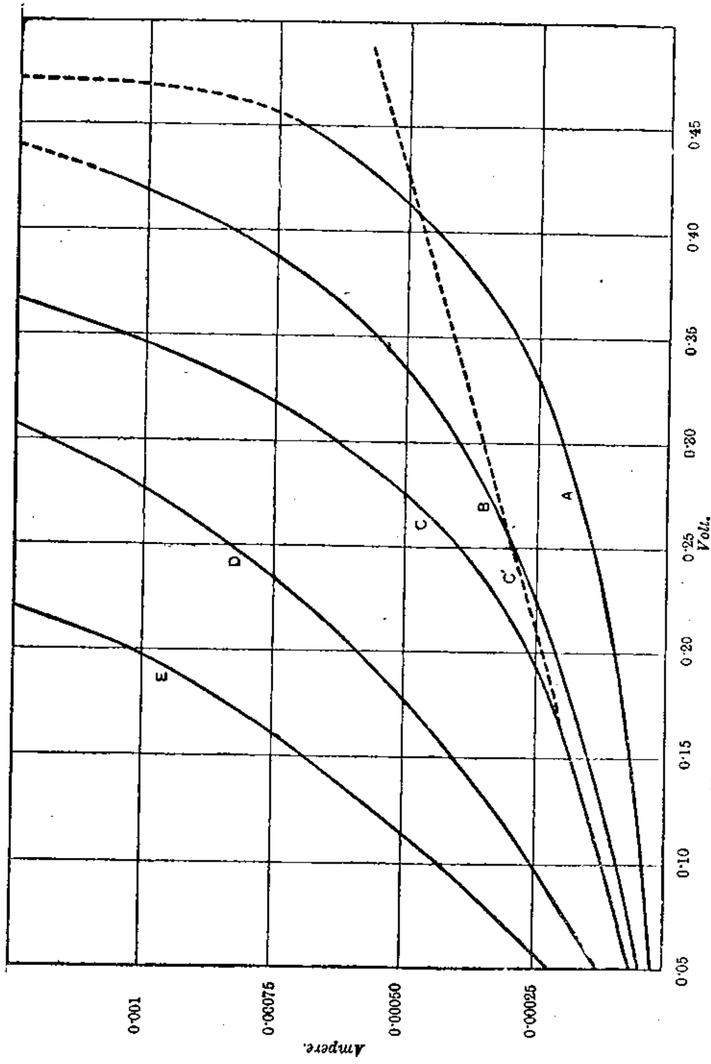

Fig. 52. Characteristic Curves of a Single Point Iron Receiver.
A, B, C, D, E are different curves for different initial currents, C' is the curve for a constant resistance.

but varies with it. A remarkable analogy is here presented with the phenomenon of magnetic con-